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A PRODUCTIVITY FUNCTION FOR WESTERN DRAGLINE OPERATIONS

by

Roger Williams Fish

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Date: 11/20/87

Signed: Roger W. Fish
Roger Williams Fish

Approved: Matthew J. Hrebar
Matthew J. Hrebar
Thesis Advisor

Golden, Colorado

Date: 11/20/1987.

M. D. G. Salamon
Dr. Miklos D. G. Salamon
Department Head
Mining Engineering

ABSTRACT

Labor productivity, herein defined as the quantity of coal produced per unit of labor expended, is a main topic in management discussions since a small improvement in operating performance can increase a mine's competitive advantage. The thesis provides two independent methods to forecast mine labor productivity at new or competing mines and to compare an existing mine's productivity with the average of the 23 dragline mines in the study. The productivity comparison allows a mine operator to determine if his mine is unproductive within the unit operations defined in the thesis or for the overall operation. These unproductive areas can then be improved by focusing on the mine factors generated in the associated productivity functions.

The first of the two methods estimates the contribution to overall mine labor productivity by general mine quantities including strip ratio, average coal lift thickness, percentage dragline rehandle material, and average weighted overburden stripping bucket capacity. The second approach separates the overall mining operation into activity groups, referred to as unit operations, in which labor requirements are forecast by more detailed factors including material volumes moved, pit dimensions, equipment capacities, and others. Both methods of analysis use multiple variable linear regression techniques to identify the contributing factors.

On the basis of residual deviation, the overall productivity regression method forecasts reality with less error than the unit operation productivity approach. A high degree of productivity variation, 87 percent, is explained by the overall labor productivity regression method when compared to previously published labor productivity estimating techniques. The unit operation method however indentifies 19 measureable

mine factors which impact labor productivity, most of which can be monitored and controlled to help improve operating performance.

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DEDICATION

The greatest motivation for completing this thesis is Pamela, whose sacrifices, love, and endless faith certainly can not be measured in tons-per-man-shift. Your pride in me and my ability transcends the written word. Because of your devotion, I dedicate these "scribblings" to you, my friend, and wife. I could not have done it without you.

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INTRODUCTION

During the past several years, a main topic in management discussions has been the importance of increasing labor productivity in order to compete more successfully in a tightening marketplace. Mine management who have experienced an increase in labor productivity have seen it directly relate to an improvement in operating profit and a stabilization in the overall work force. Thus, to improve a mine's competitive position mine personnel should focus on improving operating performance.

Numerous publications demonstrated that productivity can be improved in many areas of the mining operation. Assuming that attention to any of these areas within an operation could influence productivity, the important question becomes: which area will have the largest effect on productivity and therefore should be looked with the most attention? The thesis addresses this question and formulates a method with which to forecast and compare labor productivities for western dragline operations.

The motivation of most productivity improvement programs at a mining operation focuses on cost effectiveness and overall mine economics rather than labor productivity. Therefore, it would be best to analyze the factors which influence cost productivities. However, since data pertaining to costs is very difficult acquire from mining firms, labor productivity was investigated to assure better company participation in the study.

This thesis is one segment of research conducted for the Mine Productivity Assessment ("MPA") project funded in part by the North American Coal Company. To protect companies participating in the study, supporting data specific to individual surface coal mines is not disclosed due to the proprietary nature of the data. Only generic graphs and tables are presented in order to protect mine-specific data within an extremely competitive industry.

Thesis Definition

Utilizing data obtained from on-site surface coal mine visits within the western U.S. study area, a labor productivity function can be generated using linear regression methods in order to forecast mining labor productivities for similar existing and projected operations. The mathematical function will provide identification of measurable factors which influence labor productivity at large surface coal mines utilizing draglines for the primary means of overburden extraction. Each identified productivity factor will be investigated to determine how it contributes to productivity.

Thesis Data Acquisition

Labor productivity data were acquired in two independent phases. As part of the first phase, productivity data were collected from public domain sources including the Mine Safety and Health Administration ("MSHA"), Energy Information Administration ("EIA"), U.S. Geological Survey ("USGS"), Bureau of Labor Statistics ("BLS"), and numerous state geological and census agencies. Public domain data were acquired predominately from MSHA, with backup and supporting information from the USGS, BLS, and state agencies. A computerized database was formed from annual MSHA production-related data (coal production, employee man-hours worked, and men employed at each coal mine) during the years of 1980 through 1986, resulting in establishment of a primary productivity source for the analysis of western dragline operations.

The second phase of data acquisition extended the public domain database by requesting annual mine production and technical information from individual surface coal mines. A total of 56 mines were contacted with approximately an 80 percent approval rate for collecting annual mine data and touring the mine site. This high approval rate is a reflection of the interest coal mining firms have for determining general productivity trends and identifying the most influential factors in improving productivity. Mine data were collected for the years of 1985 or 1986, with several mines providing data for both years. The information from 1986 was inserted into the database for analysis.

Procedure For Analysis

Two independent methods of analysis are utilized to forecast labor requirements and to assess mine factors which impact labor productivity. The first method estimates the contribution of general mine quantities such as strip ratio, mine utilization, and number of coal seams to overall mine labor productivity. The second analysis separates the overall mining operation into activity groups, referred to as unit operations, in which labor requirements can be forecast by more detailed factors including material volumes moved, pit dimensions, equipment capacities, and others. Both methods of analysis use multiple variable linear regression techniques to identify the contributing factors.

Thesis Limitations

The acquisition of technical data from mining companies and the meaningful measurement of productivity at coal mines involves several major difficulties. First, the mine productivity data acquired from individual mining companies may not be accurate due to differences in interpreting the required data or in accounting procedures, although efforts were taken to fully explain the data requested. If the accuracy of a productivity factor is questionable, the interpretation of the analysis using that factor could be suspect.

A second problem in securing productivity data from western strip mines is the proprietary nature of the information gathered. Several mines did not release productivity information to the MPA project since the data could be used to approximate operating costs for the operation. In order to attain the best possible company participation, each mine has been assured that mine-specific data will be withheld so vital information is not disclosed to competitors.

A third limitation is that the development of a meaningful productivity function including all western surface coal mines may be difficult to obtain primarily due to differing stripping methods and excavation equipment used at the operations. The two primary modes of overburden excavation, dragline and shovel/truck, were separated to alleviate this problem. Hence, productivity analysis will be limited to mines with draglines producing more than one-half of all overburden removed. Difficulties may still be encountered among the dragline operations since several different stripping techniques will not be separated.

The small quantity of data could limit the ability to use common statistical methods in analyzing productivity. Also, the simulation of linear relationships in the data could be inappropriate. Transformation techniques were used to minimize this statistical limitation.

Finally, not all variables in the regression analysis are quantifiable. Many variables such as labor motivation, regulation requirements, and maintenance factors are difficult to assign values and use in the regression of productivity. Very little attention was focused on factors in maintenance and administrative operations since very few quantifiable variables could be discerned.

PRODUCTIVITY

Definitions of Productivity

It is generally accepted that the term "productivity" refers to the comparison between the quantity of goods and services produced and the quantity of resources utilized in the production of these goods and services (Fabricant, 1969). Thus, productivity is said to increase when the same quantity of resources are employed to yield a greater quantity of production. A more formal definition of productivity concerns the relationship between production and resources, or the ratio of output to input (Kendrick, 1977).

Several entities have defined specific productivities for use in comparing performance in differing industries. The most noted in the U.S. is the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor.

Bureau of Labor Statistics

As defined by the Bureau of Labor Statistics, there are two general classifications of productivity measures. The first, single factor productivity, relates output to a single type of input such as labor, capital, or energy (BLS: Bul. 2171, 1983). A useful single factor productivity measurement is computed by dividing total output by the total hours of labor (man-hours) used in production. This measure of output per man-hour is typically called "labor productivity" (Fabricant, 1969) and is used to compare the utilization of labor in an operation. This definition will be used in the thesis as the basic measurement of mine productivity because the ratio is easily understood and computed.

Single factor productivity measures exhibit the combined effect of a several factors including the substitution of one factor for another (BLS: Bul. 2171, 1983). Therefore, a shortcoming of this measurement is that it does not portray the specific contribution of individual input factors to total production.

The second, and broader classification of productivity, multifactor productivity, relates production to a weighted combination of more than one input factor to determine the productivity measure. The weights take into account the difference in performance of the input factor such as between highly skilled labor and low-quality labor. Weighting factors in this case might be the appropriate wage rates for the labor classes which quantitatively depict the difference in ability of the workforce. A similar concept is used to calculate the weight factor for any other input.

If all known input factors are weighted and aggregated, this measure is referred to as total factor productivity. Unlike single factor productivity, total factor productivity can express the joint effect of inputs on production and their interrelation in the production process.

The general framework for the measurement of multifactor productivity comes directly from the economic theory of production. The growth rate of multifactor productivity can be measured as the ratio of the growth rate of output to the average of the growth rates of the separate weighted inputs. The weight of each input factor is defined as the elasticity of the factor inputs and is computed on a consistent basis using discrete annual estimates of prices and quantities (BLS: Bul. 2178, 1983).

Confusion is substantially avoided when comparing productivity measures across industries by using total factor productivity as it accounts for changes in technology, inter-factor substitution such as labor and capital, utilization of capacity, production flow design, ability and morale levels of the labor force, and managerial skills. In addition, since each input factor is consistently weighted, relative comparisons can be made concerning productivities in differing periods and geographic locations.

Currently the BLS multifactor productivity measure uses capital and labor as inputs when comparing different industries. Future BLS work will compute total factor productivity measures based on gross output and inputs of energy, materials, and purchased services as well as capital and labor services. BLS also plans to develop measures showing changes in composition of the labor force, investment in research and development, incorporation of new technology, capacity utilization, economies of scale, and resource allocation in order to see how these factors have influenced the growth or decline of industrial productivity (BLS: Bul. 2178, 1983). These anticipated BLS multifactor productivity measures will provide a clearer understanding of the dominant input factors which influence productivity, particularly within the same industry. It will also be beneficial to determine which input factors have influenced the movement of multifactor productivity over time.

Alternative Productivity Measurements

Several alternative approaches have been utilized to measure and compare productivities within and across specific industries. The following presents the more useful methods.

Financial Ratios

Due to the differences in the physical characteristics of inputs and outputs among industries, financial ratios alleviate such differences by aggregating the inputs and outputs into financial measures. Output can be measured by total revenues or profits while inputs measured by outlays of investments. The resulting output/input ratio indicates the financial aspects of productivity relationships (Eilon, Gold, and Soesan, 1976).

Productivity Costing

This approach bases productivity measurements on the revenue or cost contributions of individual products rather than of operating units of functional activities (Eilon, Gold, and Soesan, 1976). Productivity of a product is therefore entirely represented by profitability and not the normal connotation of utilization of inputs. Productivity costing can be very useful for product marketing decisions at coal processing operations that produce many salable products.

Other Productivity Measures (Eilon, Gold, and Soesan, 1976):

- Actual output divided by either potential output or the percentage of production rejected due to incorrect manufacturing.
- Output divided by inputs with common measures (such as man-hours, cost, or capital value).
- Relating output to a "notional" or standardized output.
- Use of operational research techniques to find the limiting factors in a given productive process.

Difficulties in Measuring Productivity

Productivity, although generally understood to mean production per unit of input, is a broad and complex term which can be interpreted in different ways. Five problems confronting the measurement and use of productivity are described below (Fabricant, 1969).

(1) Output can be judged using man-hours, capital infusion, and numerous others. The result is different productivity values and correspondingly different interpretations.

(2) The measurer may influence the choice of the appropriate productivity measurement, thus perhaps clouding the real relationship.

(3) Productivity measurements and analysis can differ when comparing different periods or different countries.

(4) The method of productivity data collection and extent of data access will influence the accuracy of the productivity measurement.

(5) Productivity trends are dependent upon the period size of the trend analysis.

Purpose of Productivity Measurement

Coal operations calculate and monitor mine productivity for many different reasons. The following four points present the more important general purposes of productivity measurement [Eilon, Gold, and Soesan, 1976] which have been practiced by coal mining firms.

Strategic purposes: In order to compare the performance of the firm with that of its competitors or related firms.

Tactical purposes: To enable management to control the performance of the firm by identifying the comparative performance of individual sectors of the firm, either by function or by product.

Planning purposes: To compare relative benefits accruing from the use of different inputs, or varying proportions of the same inputs, currently and over longer periods, as the basis for considering alternative adjustments over future periods.

Other management purposes: Such as collective bargaining with trade union, assessing the effects or prospective governmental restrictions, etc.

Productivity Used in the Coal Mining Industry

Productivity measures related to the mining industry can have several definitions, but are typically measured using a short, long, or metric ton of coal product as the output unit. Input quantities utilized in the derivation of single factor and multifactor productivity measures can include capital and operating costs, revenues, labor measures, time, and numerous others.

Almost all coal mining operations use the ratio of operating costs per ton of coal to monitor the performance of the activities within the mine. Although this measure is the inverse of the generalized output/input productivity, it similarly provides information which enables management to determine how modifications to the operation have influenced operating performance. If cost data were readily available from coal mines, this type of productivity measurement would be utilized to determine the physical factors which influence mine performance.

Since mines are understandably not willing to release detailed operating costs and since labor costs are typically a large portion of the total mining cost, labor productivity is the next useful choice for productivity measurement at coal mines. Coal mines are more willing to release information related to labor. However, with the change in the basic productivity measure, the same physical factors which impact cost productivity may not have a similar affect on labor productivity.

Optimizing Labor Productivity Versus Minimizing Costs

Coal companies are generally driven by market competition to produce coal at the lowest possible cost while constrained by market opportunities and quality requirements. Thus, in their attempt to minimize overall costs and enhance cost performance, these companies may implement cost saving systems which may or may not increase labor productivity.

For example, increasing the number of motor graders to better maintain coal haulage routes could potentially reduce the cost of replacing expensive haulage truck tires and improve the cost per ton of coal produced. This decision, although perhaps reducing the overall cost of the operation, will decrease labor productivity (tons/manshift) since extra grader manpower will be required while at the same time not increasing coal production. It can be further stated that when an existing mine attempts to decrease costs by increasing labor requirements in activities which do not directly affect coal production, labor productivity will likely be reduced.

When weighing alternatives for systems which will potentially reduce total cost, the primary economic criteria of capital, operating costs, and labor must be considered. It can therefore be surmised that there is a trade off when attempting to minimize costs and optimizing labor productivity. Thus, the factors which influence operating costs may not influence labor productivity since labor is not the only cost factor important in cost minimization.

As previously stated, economic decisions are also dependent on the cost of capital required for modifying a mining process. As with operating costs there is a relationship between labor productivity and the use of capital.

Capital Influence on Labor Productivity

Microeconomic theory states that there is a general relationship between capital and labor when producing a commodity for a market (Peirce, 1986). At the unrealistic extremes, a product may be produced utilizing 100% labor or 100% capital. Between these two extremes, a company trades units of capital for units of labor, and vice-versa, in order to produce the same quantity of output. There will be a optimum point in this trade off where the minimum total cost for the project will be achieved.

Coal mines use this theory when assessing the potential for capital projects such as surface conveyor haulage or system automation. For example, if the price of capital were to increase sharply relative to labor costs, coal mines would tend to use relatively more labor and relatively less capital in the mining process. This concept is more apparent in long-term periods where the affect of changes in labor wage rates and interest rates are critical. Since the labor productivity data used in the thesis concerns only one year, a capital and labor trade off is not considered significant in the analysis.

Productivity Measurements Used

In this investigation, the primary productivity measurements on an overall mine basis will be coal tons (2,000 lbs.) per man-hour and coal tons (2,000 lbs.) per man-shift, with the latter based on an 8-hour shift. Although several operations participating in the MPA study worked 10- or 12-hour shifts, the typical 8-hour shift schedule was used for consistency. This productivity measure was selected since capital and operating cost information could not be secured from public and company sources.

When the overall mine operation is broken down into groups of activities called unit operations, performance can no longer be judged by coal tons per man-hour.

Instead, the production associated with processes within the unit operation is used as the output for the productivity measure. For example, a labor productivity measure for overburden drilling in the stripping unit operation is commonly defined as feet drilled per man-hour.

It is also meaningful to present the unit operation factor measures as the inverse, as in the case of overburden drilling: man-hours required per 1,000 feet drilled. The inverse relation (input/output) is still a labor productivity measure since it relates the activity's contribution to labor requirements.

PREVIOUS PRODUCTIVITY INVESTIGATIONS

Coal mining productivity has received considerable attention in the literature, but variations in labor productivity have rarely been studied using an empirical approach. Many publications explain productivity variations using subjective factors such as the 1969 Coal Mining Health and Safety Act and other regulations (Walton and Kauffman, 1977; Fettig, 1978; and Neuman and Nelson, 1975), labor force motivation (Bovino, 1986), and coal company ownership (Sommers, 1978). The few empirical approaches in the literature are briefly described below.

Several coal mining operations have attempted to develop internal methodologies to either compare or approximate productivities at different operations. These attempts have been fairly successful, but due to the complexity and interrelationships of the geometric and human factors involved, the results have been somewhat disputed. One of these companies, North American Coal Company, believed that there was sufficient importance to the subject to require an external study and therefore funded the MPA research project.

Oak Ridge Associated Universities published a report which defined the impact of several factors of labor productivity using aggregated values for the majority of coal mining states and mine-level data for surface and underground coal mines in Illinois, Ohio, and Pike County, Kentucky (U.S. Department of Energy, 1979). Factors used to describe productivity at individual surface mines included coal output, strip ratio (ft overburden/ft coal), injuries, mine age, and several control variables to account for strikes, idle days, and labor force employment fluctuations. A multiple linear regression analysis was performed on these variables and a productivity function was formulated.

The purpose of the Oak Ridge study was to determine the factors that had caused the decrease in productivity during the years 1966 through 1976. One result from the analysis was the moderate significance of strip ratio in the regression (t-statistic ranged from 1.38 to 2.40). This might have been caused by the non-linear relationship that the strip ratio has with productivity (see "GENERAL PRODUCTIVITY RELATIONSHIPS, Productivity Versus Strip Ratio" in the next chapter). Most significant in the regression was coal production and the control variable for the passing of state reclamation acts. It was therefore concluded that a large part of the productivity decrease was attributed to increased reclamation requirements during the period studied.

This thesis follows a similar approach in forecasting overall mine productivity, but provides a detailed productivity analysis of individual activities within the mining process. The detailed analysis provides factors which are influential to productivity.

An interesting approach utilized linear programming techniques to predict technical efficiency as defined by Farrell (1957) at 15 Illinois strip mines (Byrnes, Fare, and Grosskopf, 1984). Technical efficiency was broken down into three components: (1) a measure of input congestion, (2) a measure of scale efficiency, and (3) a measure of pure technical efficiency. Factors used in the analysis were labor-output ratio, number of coal seams, mine age, strip ratio, injuries, and equipment capacity.

It was found that efficient mines were characterized by low strip ratios, high earth-moving capacity, and multiple seams rather than single seams. The first two characteristics are very plausible, but single seam operations being less efficient is contradictory to mining theory. No explanation for the characterization was given in the report.

A recent two volume report by Carnegie-Mellon University (BOM, 1985) focused on approximating underground coal mining productivity using predominately labor and equipment delay factors. Using a multiple linear regression analysis based on mining crew output, the best regression case was able to only account for 63% of the observed productivity variation, which the report states is substantial given typical percentages reported in other literature.

The Carnegie-Mellon study failed to include the affect of mining height, cut geometry, and other physical conditions which have a major affect of overall productivity across mines. Their methodology may be appropriate when predicting crew output at one mine, but it can not be successfully applied to predicting mine productivity at different mines with dissimilar mining constraints.

In addition, there has been a tremendous amount of research and literature published on productivity impacts centered on small areas of the mining industry such as equipment maintenance and labor force organization. This material is useful in determining the factors which industry perceives important to minimize operating and capital costs, but does not quantitatively depict these factor's impact on overall mine productivity.

PRODUCTIVITY DATA ACQUISITION

Data Acquisition

Data acquired for analysis of surface coal mine productivity includes public domain and company supplied. Public domain data is available to the general public and provides information on production, mine inputs such as labor, costs, or capital, and other mine-related technical data. Potential sources of public data include MSHA, Energy Information Administration within the Department of Energy, Office of Surface Mining, U.S. Geological Survey, and numerous state geological and census agencies which collect coal mine production and employment data. The most comprehensive and computer-oriented data was acquired from MSHA.

Although the Energy Information Administration ("EIA") of the Department of Energy collects a large quantity of individual company data related to productivity (e.g. strip ratio, employee data, seam data, and excavated volumes) in the "Annual Coal Production Report" (Form EIA-7A), the EIA would not disclose company specific data beyond its published reports using aggregated information. It is believed that the EIA considers the exposure of releasing this individual data to be substantial on the premise of its concern for continuing to obtain credible data from mines.

Other Federal and State agencies which collect coal mine data typically use the MSHA reported statistics for their own coal production or geological reports. Some agencies on the state level require coal mines to report mine data similar to the data required by MSHA. In this case the state reports were used to verify MSHA data.

MSHA Data Acquisition

MSHA releases a Mine Address/Employment ("MAE") magnetic tape every quarter to the general public. This tape contains mine production and accident information collected by MSHA under Title 30 Code of Federal Regulations, Part 30. After each calendar year, the quarters are combined into a final annual magnetic tape. Annual MAE tapes are available through the Safety and Health Technology Center, Division of Mining Information Systems, located in Denver, Colorado.

The MAE tapes are divided into Coal and Metal/Nonmetal mining groups and can be requested in most any organizational form desired. Since only coal information was required for MPA research, only coal mine statistics were requested on tape for the years of 1980 through 1986.

Once the seven annual MAE tapes were received from MSHA, they were downloaded onto the Colorado School of Mines' VAX 8600A mainframe computer while eliminating all underground coal mines and surface coal mines situated east of the Mississippi River. Each coal mine record primarily contains: mine location and address, seam height, injury data, coal production, number of men employed, and man-hours worked.

The downloaded annual data on the VAX 8600A was then transferred to an IBM XT/AT microcomputer system via CSM's ETHERNET network. The raw data files in the PC environment were combined and imported into a DBASE III-Plus database, a Ashton-Tate product, for trend analysis. Following the database formation, numerous data handling and plotting routines were created to easily edit and output information from within the MSHA database.

Although the MSHA database can show trends in western surface coal mining production, manning, and productivity, it does not include variables such as strip ratio, haulage distances, pit geometry, and other influential factors on mine productivity. Additional mine-related data was needed to produce more significant results and better understanding of the components of mine productivity.

Company Supplied Data Acquisition

The MSHA database was supplemented by data supplied directly from individual surface coal mines during confidential on-site mine visits. An on-site questionnaire worksheet and a data sheet, developed prior to the mine visits and updated between the 1986 and 1987 summer tours, were used to organize the collection of productivity-related data. The questionnaire and data sheet are presented as Appendix A and Appendix B, respectively.

The individual data categories in the data sheet were formulated by reviewing theoretical mine design methods taught at the Colorado School of Mines and cost estimating publications throughout the mining and construction industries. Data categories were selected from these external sources on the basis of the variable's contribution to labor costs and unit operation production or productivity. Additional categories were provided by common knowledge of the mining process and the factors expected to influence mine labor productivity and manpower requirements.

Approximately two weeks before the a mine tour was scheduled to commence, a copy of the data sheet was typically sent to the mine to allow the engineers an opportunity to fill out the requested information on the data sheet before the mine tour. Throughout the project, mines had filled out the majority of the data sheet prior to arrival for the tour. Most mines had the sheet fully completed.

During the first several mine tours a pattern developed which became the logical sequence during mine visits. First, plan view and cross-section mine maps were reviewed so an overall layout and mining advance could be discerned. Second, a tour of the mining, loadout, and maintenance operations was conducted while completing the operation worksheet (pages 2 to 5 of Appendix A). Third, after the mine tour and while at the mine office, the philosophical questions on productivity were asked (page 1 of Appendix A). And finally, the data sheet was checked for missed or unclear responses.

With the mine tour completed, information from the data sheet was entered into a spreadsheet using Lotus Development's LOTUS 1-2-3 software and into MINITAB, a statistical computer package by Minitab, Inc., for multiple regression and unit operation productivity analysis.

Company Participation

Participation in the Mine Productivity Assessment project was unexpectedly high considering the competitive nature of the western surface coal mining industry. A total of 56 surface mines were contacted to approve data collection and mine tours. As illustrated in Table 1, of the mines contacted, 4% declined to be in the MPA study, 16% approved mine tours only, and 80% desired full participation.

The positive response to the MPA study demonstrates that there is a definite interest in productivity within the coal mining community. It is also testimony to the fact that there has been little progressive academic or corporate research into overall mine productivity and its influential variables, although many beneficial investigations and articles have been published focusing on smaller areas of productivity enhancement.

TABLE 1. COMPANY PARTICIPATION

	Number Of Mines	%	Coal Tons Represented (Thousands)	%
Western Surface Mines	--	--	302	100
Mines Contacted	56	100	259	86
Mines Declining Participation	2	4	3	1
Mines Allowing Tour Only	9	16	77	30
Mines Participating Fully	45	80	179	69
Mines with data received	35	100	174	100
Dragline	23	66	121	70
Shovel/Truck	11	31	51	29
Scraper	1	3	2	1

GENERAL PRODUCTIVITY RELATIONSHIPS

Mine labor productivity in terms of tons per man-hour is directly affected by several physical mine factors. This chapter will describe the influence of data variables collected as part of the MPA project on productivity at the mine level. In addition, analytical and conceptual relations are determined to see if these variables behave as mining theory predicts.

Productivity Versus Strip Ratio

The quantity of overburden and coal moved at an operation is generally accepted to directly affect overall labor productivity at a coal mine. The ratio of all burden moved at the operation, including rehandled material and expressed in equivalent bank cubic yards, divided by the tons of coal produced is herein defined as the strip ratio and is used as a general measure of the effort required to recover a ton of coal.

Mining theory expects labor productivity to increase as the total strip ratio decreases and decrease as strip ratio increases. Mathematically, this relationship is represented as a negatively sloped line when plotting productivity versus strip ratio. At large strip ratios, the productivity should level off since economical mines tend to have larger equipment to remove large quantities of overburden utilizing a similar quantity of men. Also, as the strip ratio reaches low values of bank cubic yards per ton, the productivity should rise dramatically as fewer men are required to strip overburden. Hence, the data trend should be curved.

Theoretically, as the strip ratio of an operation increases toward infinity, productivity should approach zero. However, as the quantity of overburden decreases to zero and the strip ratio approaches the same, productivity should reach a constant level where all activities are centered on producing coal. Although these two extremes are unrealistic, they describe the productivity curve behavior.

Figure 1 presents a subjectively fit curve and outer curves representing the range of the mine data when the overall labor productivity is plotted against strip ratio. As illustrated on the plot, the actual data basically reflects the theoretical concept.

The curve in Figure 1 can be mathematically represented as an inverse relationship with strip ratio using the form:

$$\text{Productivity} \sim (\text{Strip Ratio})^{\text{Power}}$$

Figures 2 and 3 show the result of the above plot equation by using powers of -1 and -0.5, respectively. Figure 3 is approximately linear, thus providing the estimated relationship of:

$$\text{Productivity} \sim (\text{Strip Ratio})^{-0.5}$$

The inverse relation of productivity and strip ratio can be explained by breaking the constituents of strip ratio into the defined numerator and denominator. First, productivity is proportional to the coal removed. This is realistic since the greater the coal production, the more advantage the mine has from economies of scale. The divisor component in strip ratio is overburden moved which has an inverse relation to productivity. Overburden removal activities do not produce coal and only increase the quantity of man-hours in the operation. As overburden increases, productivity (coal tons/man-hour) is reduced thus justifying the inverse relationship.

Although it is difficult to understand the square-root relation in the equation, the significance could be the mathematical explanation of how rapidly productivity changes with the change in strip ratio. Thus, a mine operator's decision to recover

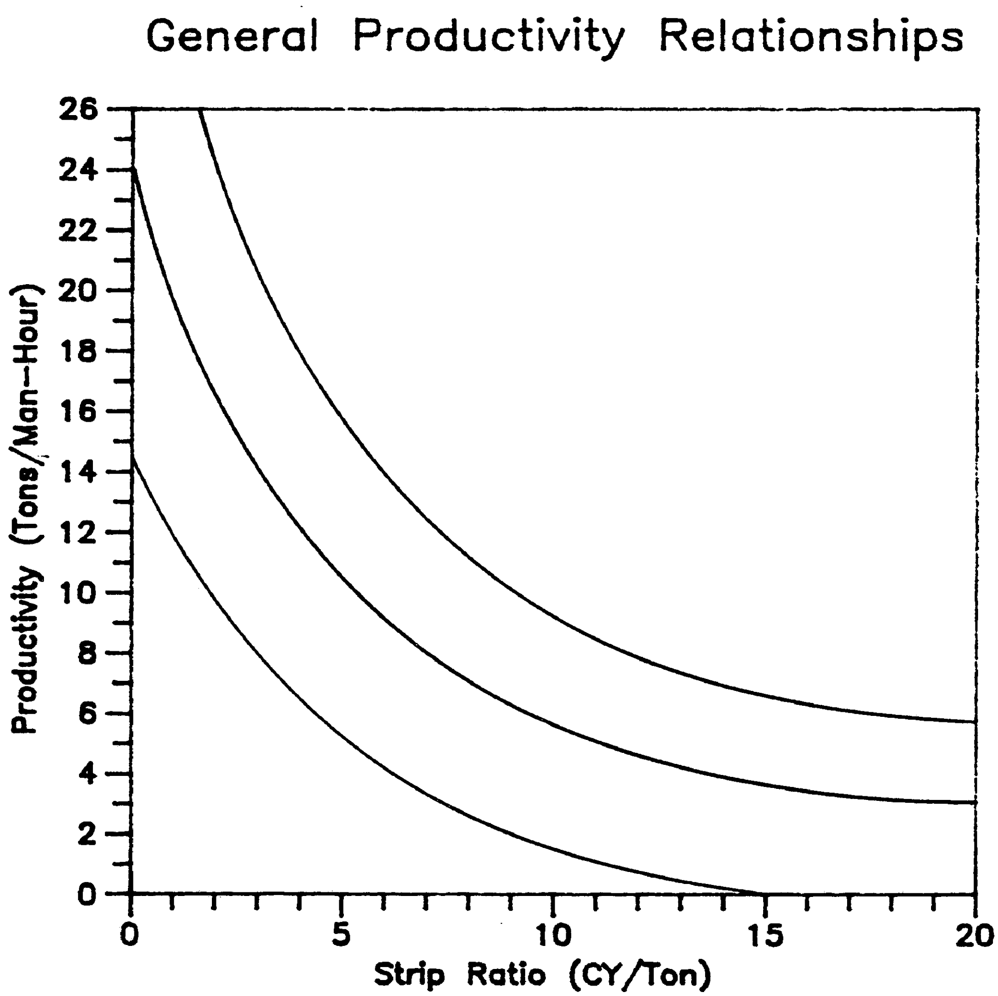


FIGURE 1. Productivity Versus Strip Ratio

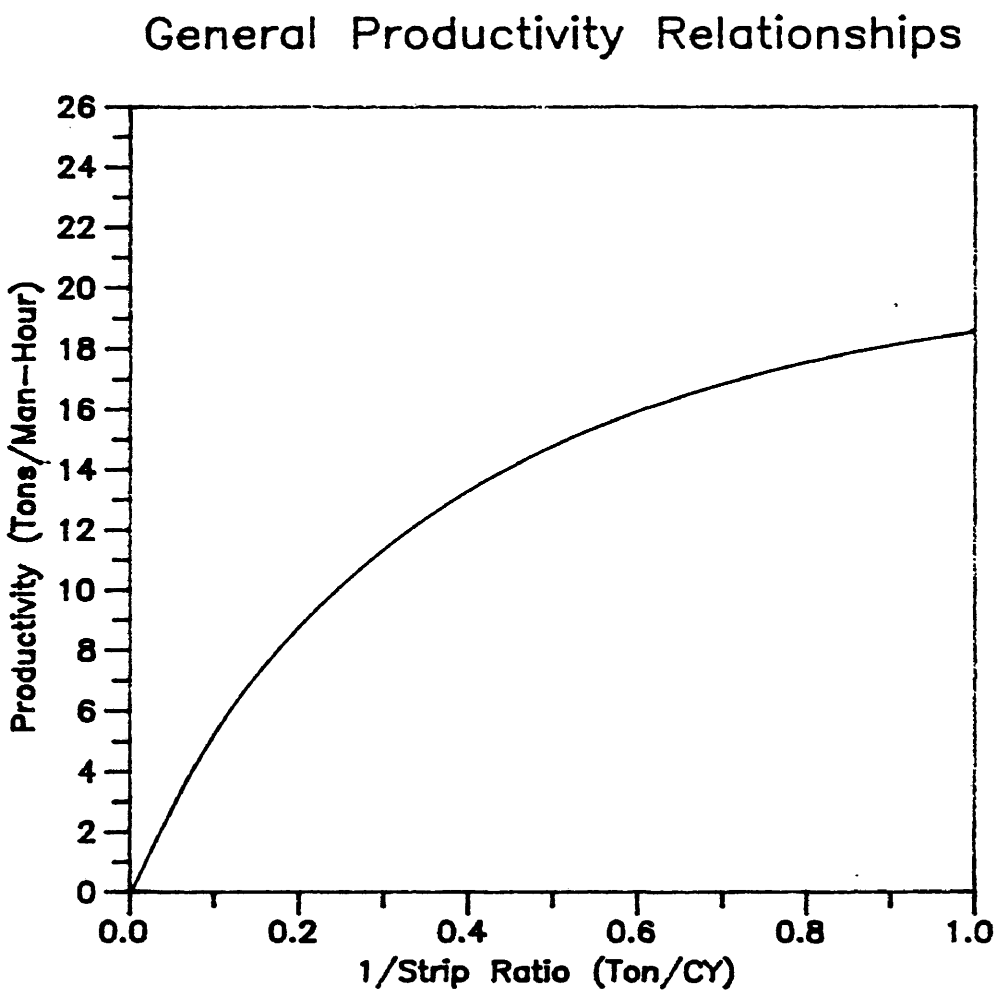


FIGURE 2. Productivity Versus (Strip Ratio)$^{-1}$

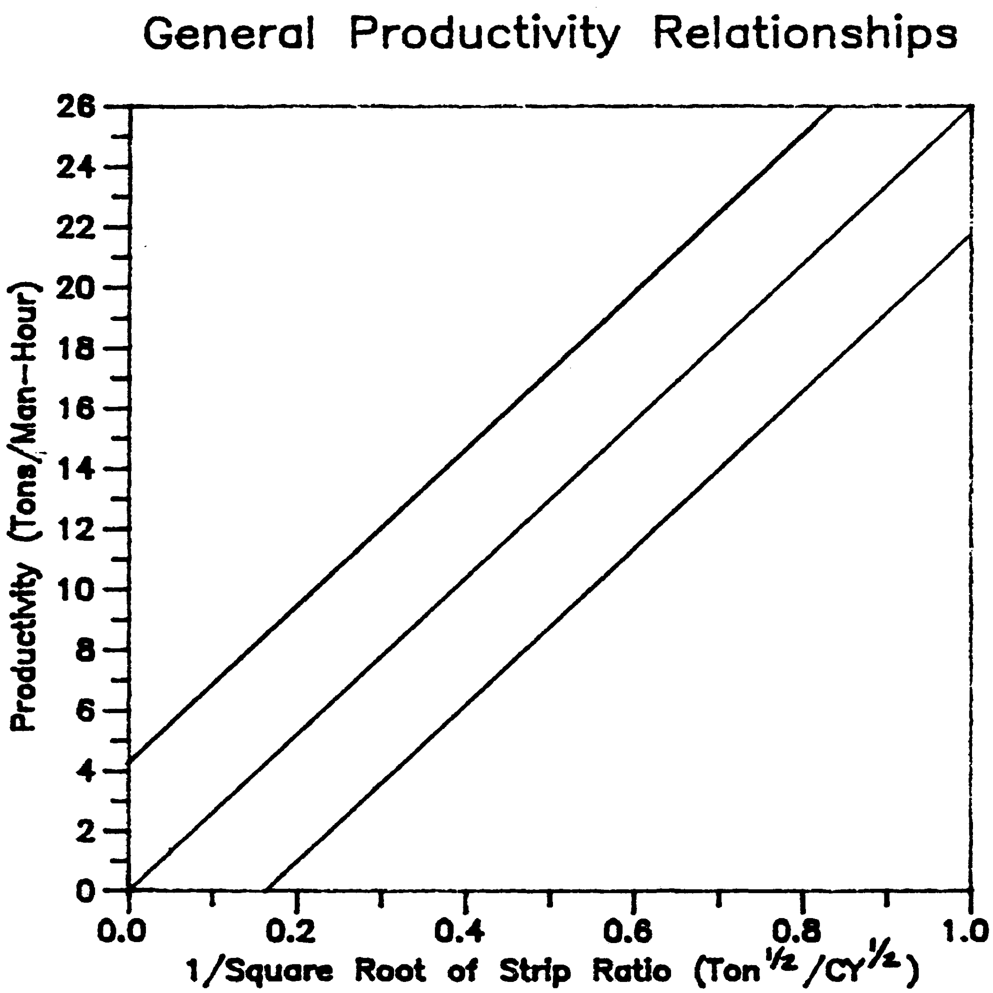


FIGURE 3. Productivity Versus (Strip Ratio)$^{-0.5}$

lower strip ratio reserves will have significant impact on labor productivity and therefore labor cost per ton of coal recovered.

Productivity Versus Average Coal Lift Thickness

Average coal lift thickness is defined as the straight average of coal seam thickness which is removed in one lift. The lift thickness was used to account for some coal mines removing very thick continuous coal seams in more than one lift. This reduces the influence of large seam operations which actually fragment and remove one coal seam as if there was more than one seam.

With all other things remaining the same, the theoretical relationship between productivity and seam thickness is one of economy of scale: larger coal seams tend to allow larger equipment and therefore greater productivity. However as the coal seam increases in height, less benefit is received from ease of bucket filling, less loader moving, and reduced face preparation. By taking only the coal lift height, the diminished returns with seam thickness should not be as apparent. In addition, when the seam thickness reaches zero, no coal is produced and productivity should theoretically be zero.

The plot of productivity versus the average coal lift thickness is presented in Figure 4. The resulting increasing trend from the origin roughly corresponds with theory. Some trail off in productivity can be seen as the coal lift height reaches approximately 25 feet resulting from possible diminishing returns or increasing strip ratio.

There is a cluster of lift thicknesses in the range of four to 12 feet where the majority of data points are located. Since all things are not equal at the participating mines, scatter is caused by factors influencing productivity such as overburden depth

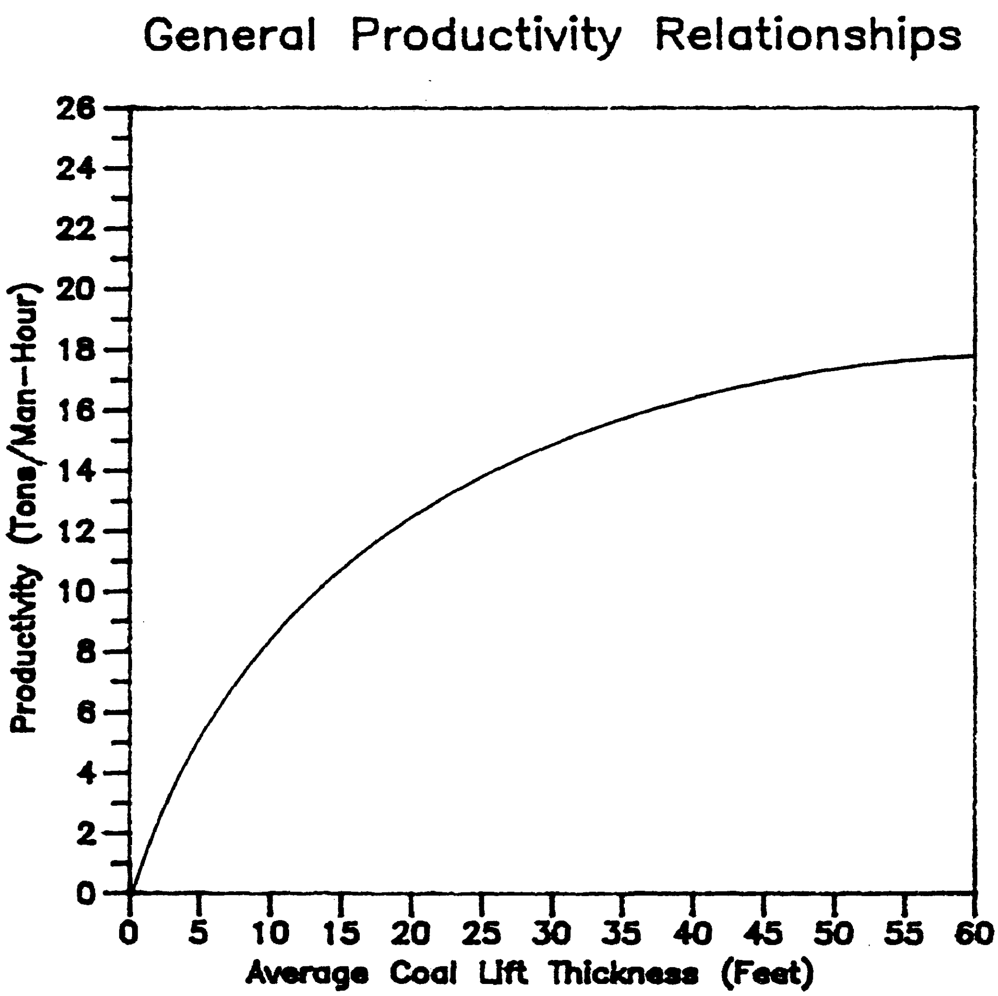


FIGURE 4. Productivity Versus Average Coal Lift Thickness

or strip ratio, number of active pits, blending requirements, and others.

Equipment Capacity Influence on Productivity

An important concept in productivity is the relation of bucket capacity with the movement of material. Output of material is directly dependent on the bucket capacity used in the operation as shown in the theoretical equation below.

Assuming the following definitions:

O = Output (volume)
K = Constant for bucket fill factor and swell (dimensionless)
BC = Bucket Capacity (volume)
T = Period of operation (time)
U = Utilization (mechanical and job factors, dimensionless)
CT = Time for one complete cycle (time per cycle)
N = Number of men required for machine operation
M = Manpower requirement for the process period (man-hours)

$$O = (K \times BC \times T \times U) / CT \qquad \text{(EQ. 1)}$$

If the equation is solved for T and multiplied through by the number of men required to operate the machine, the resulting equation estimates the man-hours for the earth-moving process. Also, by assuming that the cycle time, utilization, and machine crew size remains constant, a functional relationship can be determined.

$$T \times N = (O \times CT \times N) / (K \times BC \times U) \qquad \text{(EQ. 2)}$$

$$M = ((CT \times N) / (K \times U)) \times (O / BC) \qquad \text{(EQ. 3)}$$

or the proportional relationship,

$$M \sim K' \times (O / BC) \qquad \text{(EQ. 4)}$$

Finally, if productivity is defined as volume moved per man-hour the relationship between earth-moving productivity and bucket capacity can be described by rearranging Equation 4 into the following relation.

$$O / M \sim K'' \times BC \qquad \text{(EQ. 5)}$$

It follows from Equation 5 that the productivity of any type of earth-moving operation possesses a linear correlation with the bucket capacity. This relationship will be used in the overall productivity analysis that follows.

Equation 4 provides a relationship that will be used in the prediction of man-hours for unit operations. Man-hours for any earth-moving system is defined to be linearly related to the output divided by bucket capacity or more simply, a measure of machine cycles. This direct relation of man-hours and bucket swings will have an important role in the unit operation analysis.

As an illustrative example of the influence of bucket capacity on productivity, assume two future single seam mines will have to strip the same area to supply the correct amount of coal to their customers, but one mine has twice as much overburden to move. Using economic theory, the operations purchase draglines with bucket capacities to strip all of the overburden at full capacity. The larger operation therefore requires a bucket that is twice the volume of the bucket at the smaller mine.

The productivity (CY moved/man-hour) at the larger mine is twice that of the smaller mine since its bucket is also twice as big. Therefore, for every unit increase in bucket size there should be a corresponding increase in productivity for that particular material moving system.

Productivity Versus Other Mine Variables

There are many variables which are thought to relate to labor productivity. Almost all of the data categories provided by the 23 mines in the study were tested to see if there exists any discernible relationship with labor productivity. None of the factors exhibited a relationship due in part to the dominance of strip ratio on productivity. The following list presents the variables tested for a relation with productivity.

Cumulative Seam Thickness
Rehandle Percentage
Cumulative Overburden Digging Capacity
Average Overburden Digging Capacity
Cumulative Coal Loading Capacity
Average Coal Loading Capacity
Topographic Slope
Number of Active Pits
Pit Width
Pit Length
Spoil Angle
Highwall Angle
Overtime
Absenteeism
Union/Non-union
Age of Operation
Percentage of Coal Mine and Stripping Utilization

OVERALL PRODUCTIVITY REGRESSION ANALYSIS

Introduction

As illustrated in the preceding chapter, many factors which are expected to influence productivity are masked by the dominance of a few. The use of multiple variable regression techniques will allow these factors to become significant and enter into an equation which will forecast overall mine productivity.

Multiple Linear Regression

Multiple linear regression was used to formulate a best fit equation for productivity. For factors to be included in the regression equation, it was assumed that the observed t-statistic, a measure of the statistical significance of the regression variable, for the factor must be greater than the required t-statistic in the regression accounting for the degrees of freedom at 90% confidence.

Some factors which seem to statistically contribute to the regression equation may actually prove to be insignificant. These factors must be subjectively screened from the equation. It is also important to check if the regression coefficients have the correct slope (i.e. should the factor contribute or reduce productivity?) and the correct relative magnitude in relation to other coefficients.

A difficulty in achieving a meaningful regression equation is the existence of multicollinearity. This term basically means that there is a correlation between two or more of the independent variables in a linear regression. When the variables are correlated among themselves the data can be fit well by the regression equation but using the equation to forecast the dependent variable may not be useful or fit reality (Neter, Wasserman, and Kutner, 1985).

The stepwise regression procedure (Neter, Wasserman, and Kutner, 1985) will be used to select variables which account for the discussed regression requirements. This technique uses a search algorithm which develops a series of regression models by adding or removing independent variables until all statistically significant variables are included in the equation. Another benefit from the approach is that the variables added to the regression are deleted if collinearity exists with another variable in the model.

The stepwise function uses a F test to determine if the regression equation is statistically significant with the associated number of data points and degrees of freedom. A minimum F test value is maintained in the analysis to assure all regression models are significant.

It is possible to predict the value of an independent variable by regressing with more than one combination of independent factors. When such a case exists, selection of the best predictor equation is based on the lowest standard deviation of the dependent variable about the regression line or plane. This standard deviation (s) is an experimental approximation of the error associated with the regression and is an appropriate method of judging the effectiveness of a regression equation.

Another useful method of comparing the success of the regression equation is the value of the coefficient of determination, R^2. This value, also called the regression coefficient, provides a method of ranking significant regression models. Variation in the equation is fully described when R^2 approaches 1.0 or when all points fall on the regression equation. The coefficient of determination is less valuable however when the regression is forced through the origin in which case it should not be used for ranking the significance of regression models.

The proper method of comparing regression equations when one or more equations are forced through the origin is the use of the standard deviation or a similar value calculated by summing the squares of the regression residuals, actual data minus predicted, and dividing by the number of degrees of freedom. The latter method is used when comparing the overall productivity regression function with the productivity function determined by the unit operation approach.

Variable Selection

The variables listed below are believed to have a relation to overall labor productivity and were used in the stepwise regression analysis. Several publications (Malhotra, 1975 and U.S. Department of Energy, 1979) were helpful in the process of determining these factors and their relation to productivity.

- Strip Ratio (including all transformations)
- Average Coal Lift Thickness
- Average Seam Thickness
- Cumulative Seam Thickness
- Number of Coal Seams
- Coal Production
- Coal Acres Mined
- Disturbed Area
- Average Stripping Bucket Capacities (including all transformations)
- Overburden and Rehandle Moved by each type of removal fleet:
    - Scraper/Dozer
    - Shovel/Truck
    - Dragline
    - Bucketwheel Excavator
- Age of the Mine
- Mine Utilization
- Number of Active Pits
- Union/Non-union

These factors were tabulated for each mine and imported into the MINITAB statistical package. The stepwise command (Ryan, Joiner, and Ryan, 1976) in MINITAB was used to determine the factors which influence overall labor productivity.

Regression Analysis

Two separate approaches were used to estimate the labor productivity function using the 23 mines in the study. The first approach centered on the assumption that strip ratio is the most important factor in the description of productivity variation and after which all other uncorrelated factors are added. The second method splits strip ratio into its various parts and attempts to describe productivity variation by the more basic factors such as volumes and thicknesses. The two approaches are further described below.

Strip Ratio Approach

As discussed in the last chapter, productivity is related to the inverse of the strip ratio. Although the linear relation was estimated by the inverse of the square root of strip ratio, a better estimation can be determined by regressing the log of productivity with the log of the strip ratio. Table 2 shows the results of the regression and the determination of -0.5284 as the best fit power of strip ratio.

By using the new strip ratio transformation and the remaining factors, the result of the stepwise regression using a constant is presented in Table 3. The column "Theoretical Sign" shows the dictated sign from the reality of the strip mining process. Since productivity should increase as the weighted average bucket size of stripping shovels increases, the sign of this variable's coefficient is incorrect and therefore shovel bucket size must be dropped from the analysis. Also the t-statistic for the constant is less than the required t-statistic and can be eliminated from the model since it is not statistically different from zero.

By screening out incorrect variables, transformed strip ratio becomes the only significant factor in overall labor productivity with a standard deviation of 2.29

TABLE 2. STRIP RATIO TRANSFORMATION

Factor definitions:
LOLP = Log of the overall labor productivity for the mining operation
LSR = Log of the strip ratio
C = Regression constant

Regression:

Predictor	Coefficient	Std. Dev.	T-Statistic
C	2.9671	0.1468	20.21
LSR	-0.5284	0.7991	-6.61

$R^2 = 0.676$
S (std. dev.) = 0.2559

Equation:
LOLP = 2.9671 - 0.5284(LSR)
Range of predictor LOLP = +/- 0.421 (90% Confidence)

TABLE 3.
STEPWISE REGRESSION OF TOTAL MINE MAN-HOURS -
STRIP RATIO APPROACH

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3
Constant	(0)	-0.4481	-0.1247	1.3764
T-STATISTIC		-0.35	-0.11	1.12
Strip Ratio(1)	(+)	21.1	22.5	23.5
T-STATISTIC		7.68	8.84	10.06
Shovel CY Cap.	(+)		-0.108	-0.128
T-STATISTIC			-2.41	-3.11
1/Drag CY Cap.	(-)			-84
T-STATISTIC				-2.36
Standard Deviation		2.34	2.11	1.91
R-Squared (%)		73.75	79.65	84.27

(1) Strip Ratio is tranformed by raising it to the -0.5284 power.

tons/man-hour. Tables 4 and 5 reflect the correct stepwise regression and productivity function without shovel bucket size and no constant, respectively. The following presents the final productivity function using strip ratio as the basis for analysis.

$$\text{Productivity} = 20.25(\text{Strip ratio})^{-0.5284}$$

Figure 5 represents the plot of the strip ratio productivity function including a 90% confidence range. Also, the graph of forecast versus actual productivity is presented to display the fit of the forecasting function.

The meaning of the coefficient and power constants of the strip ratio variable in the regression is difficult to determine. Mathematically, the constants describe the

TABLE 4.
FINAL STEPWISE REGRESSION OF TOTAL MINE MAN-HOURS - STRIP RATIO APPROACH

Factors/T-stat.	Theoretical Sign	Case *1*
Constant	(0)	0
T-STATISTIC		-
Strip Ratio(1)	(+)	20.3
T-STATISTIC		19.83
Standard Deviation		2.29
R-Squared (%)		74.3

(1) Strip Ratio is tranformed by raising it to the -0.5284 power.

TABLE 5.
OVERALL PRODUCTIVITY FORECASTING FUNCTION - STRIP RATIO APPROACH

Factor definitions:
OLP = Overall labor productivity for the mining operation
TSR = Strip ratio raised to the -0.5284 power

Regressions:

Predictor	Coefficient	Std. Dev.	T-Statistic
TSR	20.25	1.021	19.83

S (std. dev.) = 2.293

Equation:
OLP = 20.25(TSR)
Range of predictor OLP = +/- 3.77 tons/man-hour (90% Confidence)

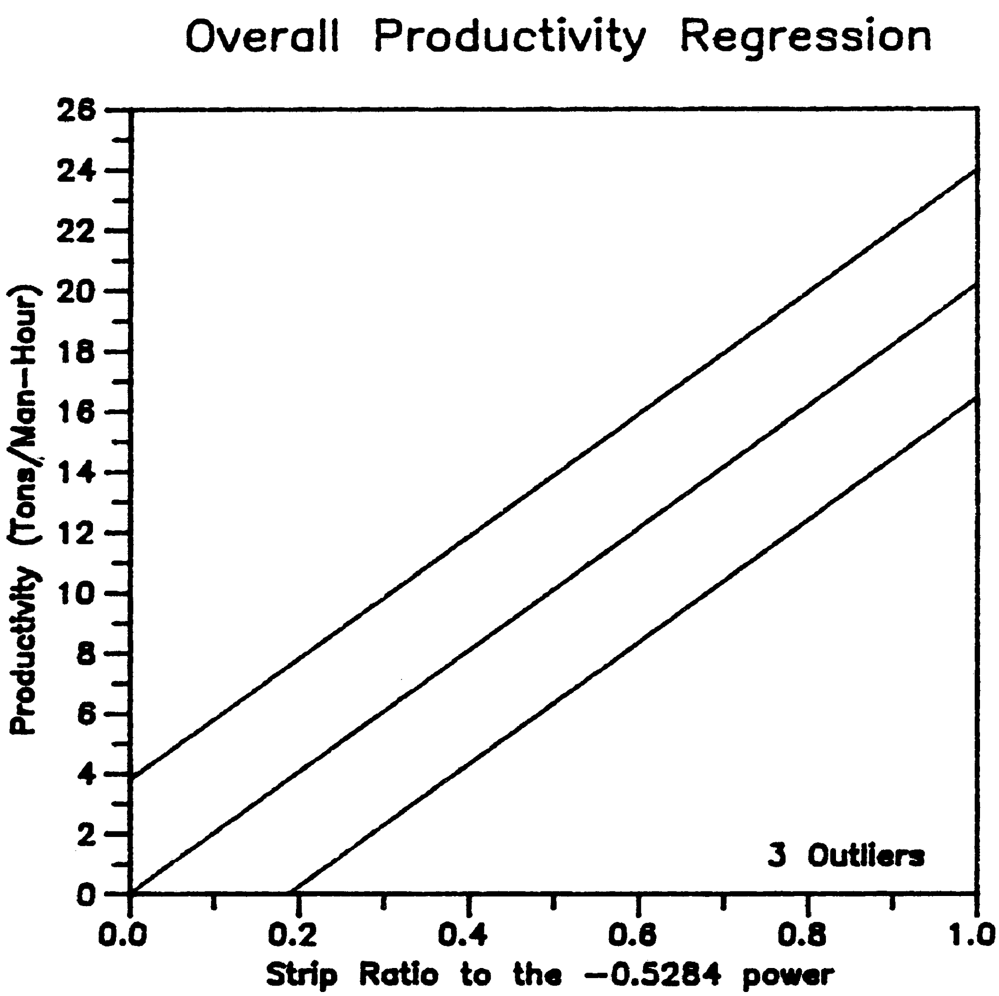


FIGURE 5. Productivity Versus (Strip Ratio)$^{-0.5284}$

non-linear rate at which productivity drops with increase in strip ratio. However it can be assumed that due to the inverse nature of the relationship productivity is decreased rapidly as strip ratio increases at lower strip ratios, but tends to level off at higher ratios.

The regression coefficient of 74.3% for the regression of productivity with strip ratio is believed to be quite good in relation to other productivity studies reviewed. Strip ratio seems to be a fair judge of the productivity at an operation only if it is transformed to allow linear regression techniques to fit a model to the data. The non-linear relationship of productivity with strip ratio was overlooked by most previous productivity studies including strip ratio as a primary variable and could be a reason for their lower R^2 values.

Basic Factors Approach

In the second approach, productivity is regressed on more fundamental mining factors such as overburden depth, coal thickness, and material volumes extracted. The basic idea was to yield a constant which represented the maximum productivity for mining coal and reduce this constant by factors involved with unproductive operations. The maximum coal productivity should also be modified by factors like coal height, acres mined, and loading capacity, while the unproductive activities should vary with overburden depth, disturbed area, bucket capacity, and material volumes.

Table 6 shows the results of the stepwise regression using the basic production factors. Shovel bucket capacity and the inverse of the dragline bucket capacity resulted in the incorrect slope and were eliminated. The final regression statistics and productivity function are exhibited in Tables 7 and 8. The productivity forecasting equation below is the result of the basic factor regression approach and achieved a standard deviation of 1.73 tons/man-hour and a R^2 value of 87.0%.

OLP = 8.921 + 0.3876(ACL) - 19.03(DR%) - 65.59(IOBC) where:
OLP = Overall Labor Productivity
ACL = Average Coal Lift Thickness
DR% = Dragline Rehandle Material as percentage of Dragline BCY moved
IOBC = Weighted average overburden stripping bucket capacity (CY) (draglines and shovels)

TABLE 6.
STEPWISE REGRESSION OF TOTAL MINE MAN-HOURS - BASIC FACTORS APPROACH

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3	Case 4	Case 5
Constant	(+)	4.079	7.147	6.653	8.492	14.807
T-STATISTIC		5.02	7.17	7.14	7.46	4.93
Avg Coal Lift	(+)	0.376	0.386	0.415	0.419	0.420
T-STATISTIC		7.30	9.71	10.82	12.17	13.51
Drag % Rehandle	(-)		-17.1	-11.9	-14.2	-13.5
T-STATISTIC			-3.94	-2.62	-3.39	-3.55
Shovel CY Cap.	(+)			-0.097	-0.102	-0.157
T-STATISTIC				-2.28	-2.67	-3.70
1/Drag CY Cap.	(-)				-68	-184
T-STATISTIC					-2.38	-3.18
Avg OB CY Cap.	(+)					-0.063
T-STATISTIC						-2.24
Standard Deviation		2.43	1.87	1.70	1.52	1.38
R-Squared (%)		71.7	84.1	87.5	90.5	92.7

TABLE 7.
FINAL STEPWISE REGRESSION OF TOTAL MINE MAN-HOURS - BASIC FACTORS APPROACH

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case *3*
Constant	(+)	4.079	7.147	8.921
T-STATISTIC		5.02	7.17	7.10
Avg Coal Lift	(+)	0.376	0.386	0.388
T-STATISTIC		7.30	9.71	10.54
Drag % Rehandle	(-)		-17.1	-19
T-STATISTIC			-3.94	-4.62
1/OB CY Cap.	(-)			-66
T-STATISTIC				-2.08
Standard Deviation		2.43	1.87	1.73
R-Squared (%)		71.7	84.1	87.0

TABLE 8.
OVERALL PRODUCTIVITY FORECASTING FUNCTION -
BASIC FACTOR APPROACH

Factor definitions:

OLP = Overall labor productivity for the mining operation
ACL = Average Coal Lift Thickness (feet)
DR% = Dragline Rehandle Percent (rehandle BCY/bank BCY)
IOBC = Inverse of the weighted average bucket capacity for overburden removal equipment (1/CY)

Regression:

Predictor	Coefficient	Std. Dev.	T-Statistic
C	8.921	1.256	7.10
ACL	0.38759	0.03676	10.54
DR%	-19.034	4.119	-4.62
IOBC	-65.59	31.49	-2.08

R^2 = 0.870
S (std.dev.) = 1.728

Equation:

OLP = 8.921 + 0.38759(ACL) - 19.034(DR%) - 65.59(IOBC)
Range of predictor OLP = +/- 2.843 tons/man-hours (90% Confidence)

The productivity function for the basic factors approach yields a equation similar to the conceptual model. The constant is large and positive, with productivity increased by 1.0 ton per man-hour for every 2.6 feet of coal lift height. The combination of the regression constant and the coal lift height represent the maximum productivity an operation could attain if activities centered only on mining coal. This maximum coal productivity is then reduced by the amount of rehandled dragline overburden and the inverse of stripping capacity.

In reality, the two overburden variables explain a large portion of the productivity reduction at an operation. Usually a sizable quantity of overburden must be stripped at an operation to uncover coal. If a mine has larger stripping capacity, it can uncover more coal per stripping man-hour than a mine with lower capacity. Therefore the inverted stripping capacity is sensible since the reduction in labor productivity (coal tons/man-hour) is not as great for larger bucket sizes. The dragline rehandle percentage is important also due to the lower productivities associated with rehandled material.

The coefficients for the two productivity reduction terms probably include the effect of other unproductive activities. Thus, interpreting these values could be misleading. The remainder of variation in the regression model is explained by the importance of these other unproductive factors in productivity.

Regression Results

The standard deviations (s in Tables 5 and 8) of the two overall productivity forecasting equations are compared to determine the best predicting function of overall labor productivity. The s values for the strip ratio and the basic factor models are 2.29 and 1.73, respectively. Since the basic factor model has the lower standard deviation, this method will be utilized as the overall labor productivity forecasting formula. Figures 6 and 7 display the plot of forecast productivity versus actual productivity for the mines and the forecast/actual ratio of productivity, respectively.

Method Application

Applying the overall productivity function for western dragline mines yields an expeditious solution to the frequently asked question: how does the labor productivity

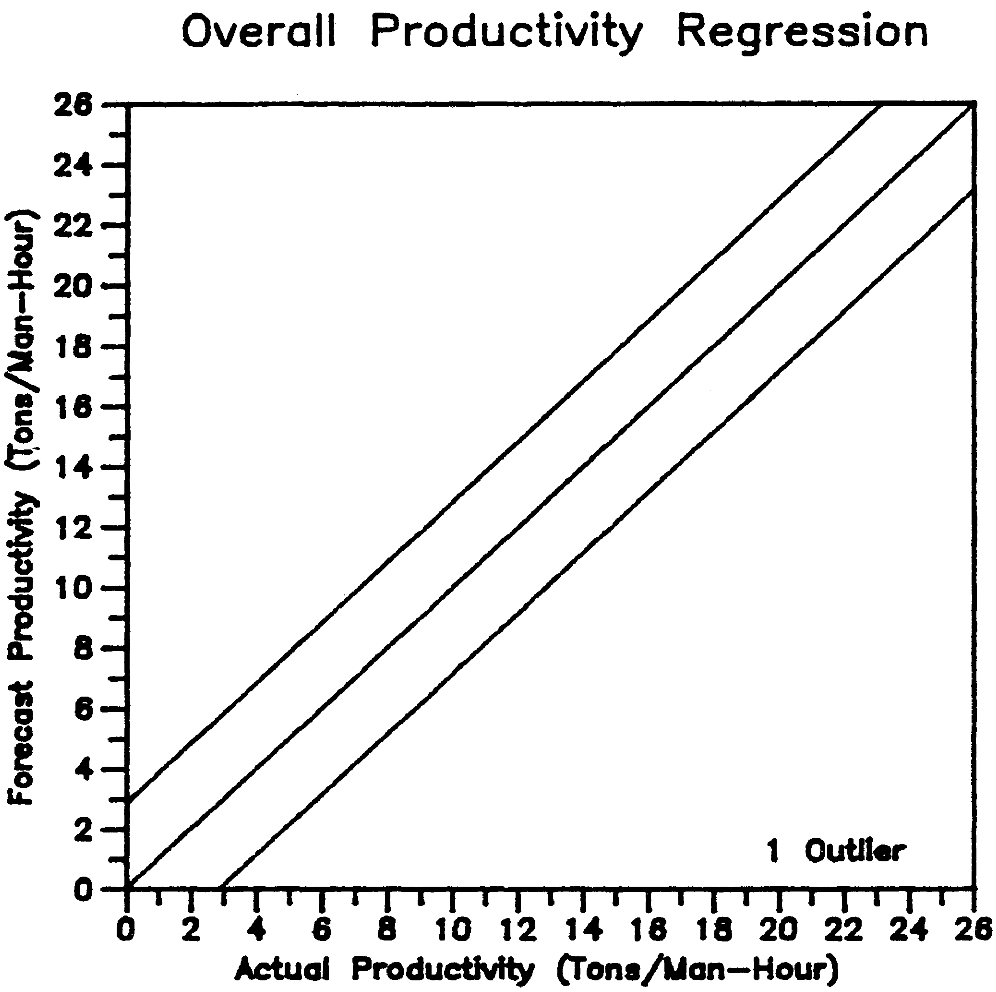


FIGURE 6. Forecast Versus Actual Productivity - Overall Productivity Regression

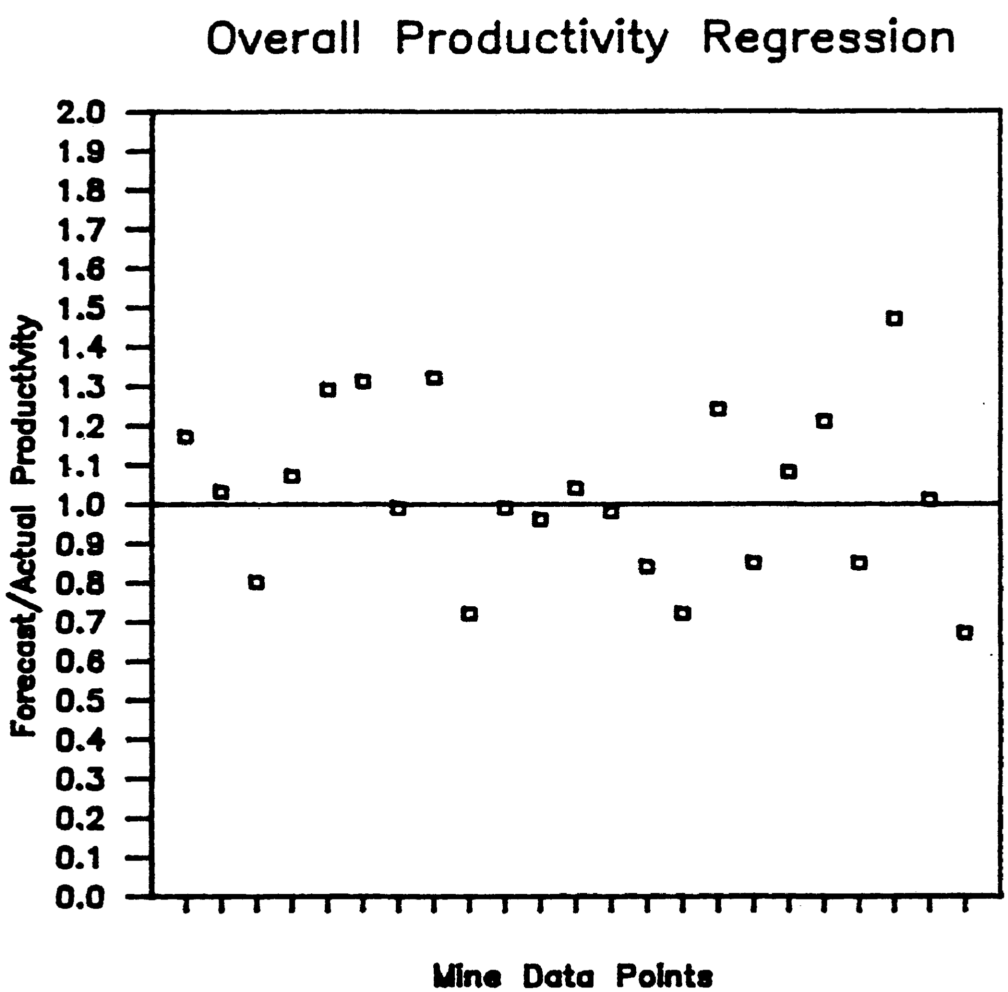


FIGURE 7. Forecast/Actual Productivity Plot - Overall Productivity Regression

at one operation relate to that of a competitor's? To apply the model, the values of average coal lift thickness in feet, dragline rehandle as a percentage of all CY moved, and the total average overburden stripping bucket capacity in cubic yards weighted by BCY moved must be determined or approximated for each operation. Next, these values must be modified by the appropriate coefficients and powers in the following forecasting equation and summed to obtain the predicted labor productivity. The resulting estimated productivities can be compared to determine which mine is potentially more productive.

OLP = 8.921 + 0.3876(ACL) - 19.03(DR%) - 65.59(IOBC) where:

OLP = Overall Labor Productivity
ACL = Average Coal Lift Thickness
DR% = Dragline Rehandle Material as percentage of Dragline BCY moved
IOBC = Weighted average overburden stripping bucket size (draglines and shovels)

In the case of estimating productivity for a future or existing mine, the procedure is exactly the same except that an error term must be added to account for the amount of confidence in the estimation. For the productivity function, a predicted value will lie in the range of approximately (+/-) 2.84 tons per man-hour, 90 percent of the time. Other confidence intervals can be calculated by multiplying the the standard deviation of the productivity forecasting function (1.728 tons per man-hour) by the t-statistic for the associated confidence limit.

Method Conclusions

In relation to previous work, the description of 87% (value of R^2) of the variation in mine productivity is very high. One possible reason for lower regression coefficients in other work could be the assumption of linearity for all factors involved.

As seen in the final productivity function, an inverse relationship is encountered for the average stripping bucket size.

The three factors having mathematical influence on forecasting overall productivity are judged to actually have significant impact on the performance of a operating mine. In addition, the concept of an operation having a maximum coal productivity which is reduced by unproductive activities seems to mathematically model the real mining process quite well.

Although the strip ratio approach proved to have less accuracy than the basic factors model, the influence of strip ratio on labor productivity is an important relationship. One important conclusion is that strip ratio does not have a linear contribution to productivity. Instead, the relationship is curvilinear with a good approximation being the inverse of the square root.

Most importantly, this method can be used to forecast productivity with very little effort and detailed knowledge of an operation. The forecast does however have limitations since the three variables do not account for 13% of the variation of the data producing the function. A breakdown of the productivity quotient into its parts should reduce the variation.

UNIT OPERATION PRODUCTIVITY MODEL

Introduction

Associated with the measure of overall labor productivity are many factors which are not significant in the statistical analysis but are expected to be influential from common knowledge of the mining process. In order to utilize other factors to describe productivity, the overall mining process was broken down into groups of related mining activities referred to as "unit operations". The man-hours associated with each unit operation was then analyzed using linear regression methods to identify any other contributing factors.

Unit Operation Definitions

Nine unit operations were defined to separate related activities with Figure 8 illustrating the breakdown. When man-hours are predicted for each unit operation and then summed, an alternative method of approximating overall mining labor productivity is created by dividing the projected coal production by the forecast man-hours. Table 9 presents the definition and associated activities for each unit operation.

Employment of contractors for mining duties is a cost to an operation and is not typically included in public domain labor productivity measures or man-hours. If not considered, these additional man-hours artificially increase productivity. For the purpose of this study, estimated contractor work in man-hours was included in each unit operation for which the work was done. Similarly, other outside mining assistance such as division and corporate services, local farmer reclamation, and contract maintenance was included in manpower measures whenever possible.

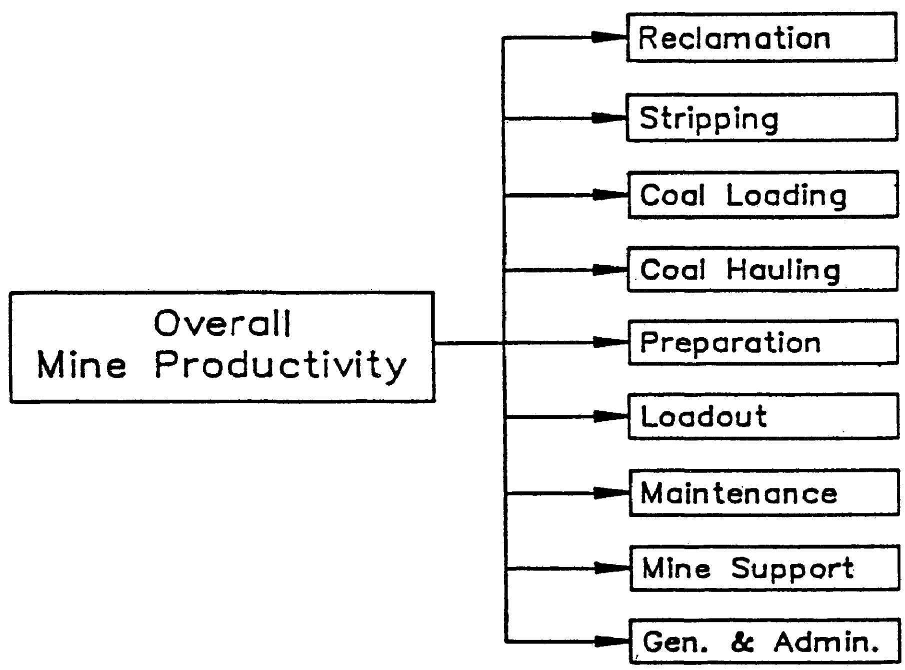


FIGURE 8. Mine Productivity Breakdown Chart

TABLE 9. UNIT OPERATION DEFINITIONS

Reclamation:
Soil removal and replacement, spoil regrading, reclamation, environmental monitoring, pond construction and maintenance.

Stripping:
Drill and blast overburden, bench preparation, overburden and interburden removal.

Coal Loading:
Cleaning coal seam, drill and blast or rip coal (fragmentation), load.

Coal Hauling:
Hauling coal to a dump point.

Coal Preparation & Loadout:
Crushing, screening, washing, and blending coal production. Also coal product loading into final transport including overland conveyor systems.

Maintenance:
All equipment and facilities.

Mine Support:
Road maintenance, pit and aquifer pumping, utility ash disposal, all other direct mine support activities not listed above.

General & Administrative (G&A):
Upper management, engineering, office, corporate.

NOTE: All unit operation supervision is included in the associated unit operation.

Another potential problem in the unit operation analysis in the inclusion of maintenance man-hours within other unit operations. One coal mine in the study charged the majority of maintenance man-hours attributed to individual pieces of equipment directly to the activity in which the machine was operating. Since this maintenance accounting procedure was inconsistent with the remainder of studied strip mines, the data point was not included in the unit operation analysis. The point was included however in the total operation man-hours since the spreading out of maintenance man-hours among unit operations should cancel out when the man-hours are summed for the entire mine.

Preparation and loadout operations will be excluded from the regression analysis since these activities are dependent on external factors such as market location and length of coal contract. Only general plots and conclusions are presented for the preparation and loadout unit operation.

Method of Analysis

The primary factors believed to influence the quantity of man-hours expended at each unit operation will be defined and a conjectured relationship between each factor and its associated labor requirement will be examined. If an analytical expression can be developed which mathematically determines unit operation man-hours, the expression will be used to help describe the relationship between man-hours and the variables included in the expression.

Multiple variable linear regression will be utilized to ascertain a function to predict each unit operation's man-hours. A stepwise algorithm assuming a minimum 90% confidence will be used to determine all significant factors and possible regression models for the unit operation. The unit operation forecasting function will be selected from the possible models on the basis of lowest standard deviation and inclusion of the appropriate regression factors. The plot of regression residuals, the difference between the actual and forecast man-hours, will determine if a trend exists indicating that the regression equation may not be linear as assumed.

The man-hours forecast by the selected regression model for each unit operation will then be added together to estimate the total man-hours for the mine. By dividing the actual coal tons by the forecast labor requirement, an overall labor productivity is determined and can then be compared with the productivity function generated in the last chapter.

Unit Operation Size

The ability of the unit operation analysis to effectively forecast man-hours at a mine is partially dependent on the close approximation of man-hours for unit operations with the largest labor requirements. The table below represents the actual average and range of man-hours utilized in each unit operation for all mines in the study excluding the one mine which accounted maintenance labor in other unit operations.

As illustrated by the preceding table, the maintenance and G&A unit operations contain the most man-hours and therefore are very important to the success of the

TABLE 10. PERCENTAGE MAN-HOURS FOR UNIT OPERATIONS

Unit Operation	Percent of Total Man-hours	Range
Maintenance	30.6	13.5 - 38.3
G & A	22.2	12.2 - 37.8
Stripping	16.6	7.8 - 27.6
Coal Hauling	7.2	2.3 - 24.0
Mine Support	6.8	3.4 - 14.4
Reclamation	6.4	1.8 - 19.7
Preparation & Loadout	5.2	0.0 - 14.6
Coal Loading	5.0	1.5 - 9.0
Total	100.0	

analysis. If these activities are accurately forecast, the man-hour function should be meaningful. If not, the unit operation analysis might have less accuracy than the overall productivity regression method presented in the last chapter.

Analysis Presentation

Each unit operation was analyzed separately in the following sections. The overall productivity will be computed after all of the unit operation man-hour forecasting functions have been determined. The analysis of unit operations will have the following organization.

(1) Define the activities and typical job classifications associated with the unit operation.

(2) List all factors used in the stepwise regression.

(3) Describe primary factors thought to have greatest impact on unit operation labor requirements. Define the theoretical behavior of man-hours with a change in each primary factor (slope, man-hour intercept, linearity, transformations to simulate linearity). Also, present any deterministic equations that can be developed for the unit operation which describe the impact of mine variables on unit operation labor requirements.

(4) Display all significant man-hour models produced by stepwise regression and select the of most appropriate forecasting equation.

(5) Discuss significant and insignificant primary factors in the analysis. Present reasons for remaining variation after regression.

Reclamation Unit Operation Analysis

Reclamation Definition

Reclamation activities are defined to include: removal, stockpiling, and replacement of topsoil and subsoil, spoil peak rough grading, final spoil regrading, reclaiming disturbed areas to original conditions, environmental monitoring, and maintaining drainage. Possible job classifications for this unit operation are listed below.

- Scraper operator
- Dozer operator
- Motor grader operator
- Backhoe operator
- Front-end loader operator
- Truck operator
- Tractor and implement operator
- Ditching operator
- Reclamation foreman
- Reclamation supervisor
- General labor

Regression Factors

The table below lists the quantitative factors tested in the regression analysis of annual man-hours expended for reclamation activities.

TABLE 11. RECLAMATION VARIABLES

Topsoil thickness (inches): all soils that must be handled separately
Topsoil moved (BCY): including all rehandled topsoil
Disturbed area (acres): area where topsoil has been removed
Control variable: 0 = greater than 50% of topsoil is directly respread
1 = less than 50% of topsoil is directly respread
Pit dimensions:
Spoil angle (degrees)
Pit width (feet)
Pit Width x TAN[Spoil Angle]
Pit length
Overburden depth
Topography angle (degrees)

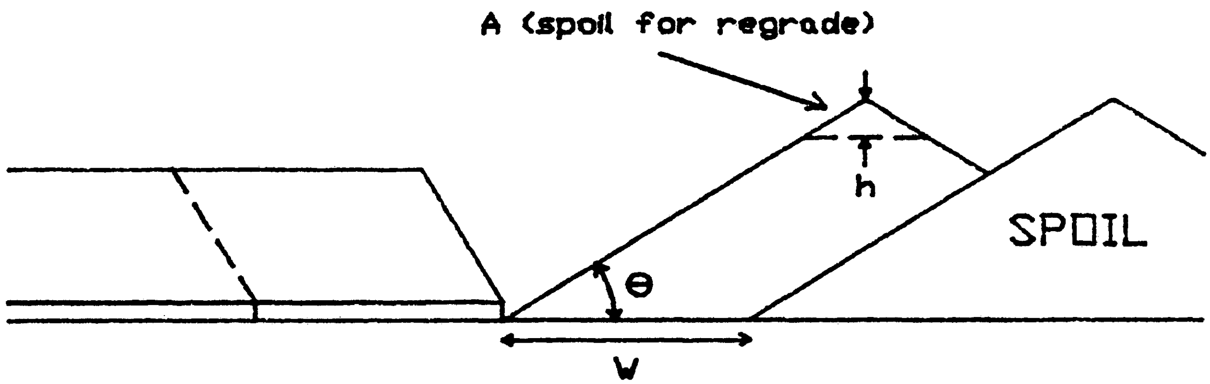
Primary Reclamation Variables

Topsoil Volume Moved: This factor can be estimated in two ways. First, the quantity of topsoil moved should indicate the contribution to reclamation man-hours by topsoiling operations. The quantity of topsoil moved can also be estimated by the combination of disturbed area and topsoil thickness with exception of topsoil stockpiled and rehandled. By including the control variable representing direct topsoil replacement, total topsoil volumes can be approximated.

Topsoiling man-hours should increase as more topsoil volume is moved. When no topsoil is moved, no man-hours are needed for the operation, thus forcing the relationship through the origin. Since scrapers typically move topsoil by removing a constant lift thickness, the increasing trend of man-hours with increasing topsoil volumes should be constant.

Spoil Regrading: The quantity of material that must be moved to approximate the original topography is a function of the area disturbed for topsoiling if contemporaneous reclamation is assumed. This assumption was not always the case, as many operations in the study were either behind or far ahead of regrading requirements. However if a relationship exists with disturbed area, the slope should be positive, approximately linear, and pass through the origin.

Pit geometry factors including spoil angle, pit width, overburden depth, and topography slope also contribute to the volume of regraded spoil. As seen in Figure 9, the volume of spoil to be regraded per foot of pit length (into the figure) and per foot of pit advance has a linear relationship with pit width and spoil angle. The equation also shows that the multiplicative relationship of pit width times the tangent of spoil angle exists and passes through zero.



$h = (W/4)\tan\Theta$

$A = (1/2)(1/2\ W)(W/4\ \tan\Theta)$

Volume per Ft of Advance and Pit Length $= (1/16\ W^2 \tan\Theta)\ /\ W$
$= 1/16\ W \tan\Theta$

Volume per Ft of Advance and Pit Length $\sim K\ W \tan\Theta$

FIGURE 9. Spoil Regrading Requirements

Reclamation: When contemporaneous reclamation is assumed, reclamation (i.e. establishment of vegetation) should be directly related to the area disturbed for topsoil removal. The slope of man-hours versus disturbed area should be positive and constant, with the line going through the origin.

Reclamation regulations vary widely among the western states (Office of Technology Assessment, 1986). Because of this fact, the contribution of revegetation activities to the total unit operation man-hours can not be quantitatively defined. The possible variation in regulation requirements will have a significant effect on this factor's impact on total man-hours for the reclamation unit operation.

Reclamation Regression and Equation Selection

A stepwise regression was performed on reclamation man-hours utilizing all factors listed in Table 11. Table 12 presents all regression models describing a significant portion of variation in man-hours. Significance was was determined to exist with three factors: disturbed area, topsoil thickness, and the control variable representing direct topsoil replacement.

All regression variables had the correct theorized sign and behaved as speculated. Residuals from the regression had no discernible trend thus confirming the assumption of linearity. Since all three factors had significance and responded as theory suggests, Case 3 in Table 12 was selected to forecast total reclamation man-hours. Table 13 presents the statistics from the regression of Case 3 which yielded a standard deviation of 10,906 man-hours.

The result of plotting forecast reclamation man-hours versus the actual man-hours is presented as Figure 10. If the predictor function explained all of man-hour variation, all data points should fall on a line radiating from the origin with a 1:1

TABLE 12. STEPWISE REGRESSION OF RECLAMATION MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case *3*
Constant	(0)	0	0	0
T-STATISTIC		-	-	-
Disturbed Area	(+)	152.9	131.7	125.7
T-STATISTIC		13.93	13.88	15.10
Direct Respread	(+)		20397	15591
T-STATISTIC			4.30	3.58
Topsoil Thickness	(+)			274
T-STATISTIC				2.94
Standard Deviation		17358	12822	10906
R-Squared (%)		-	-	-

TABLE 13. RECLAMATION MAN-HOUR FORECASTING FUNCTION

Factor definitions:

RMH = Man-hours required for reclamation unit operation
DA = Disturbed Area (acres disturbed for topsoil removal)
TT = Topsoil thickness (inches)
DR = Dummy variable to relate whether direct replacement of topsoil is performed, where:
0 = greater than 50% direct topsoil replacement
1 = less than 50% direct topsoil replacement

Regression:

Predictor	Coefficient	Std. Dev.	T-Statistic
DA	125.691	8.325	15.10
TT	274.28	93.29	2.94
DR	15591	4354	3.58

S (std.dev.) = 10,906

Equation:

RMH = 125.7(DA) + 274.3(TT) + 15,591(DR)
Range of predictor RMH = +/- 17,940 man-hours (90% Confidence)

slope. The shaded portion of the graph represents the area where a forecast will be located 90% of the time and was determined by multiplying the regression standard deviation by the published value representing 90% of the area under the normal distribution curve, or 1.645. This range, +/- 17,940 man-hours, is quite large in relation to the average reclamation man-hours of 47,687 man-hours for the mines in the study.

Reclamation Factor Analysis

Several things can be projected from the selected regression model. Since topsoil thickness, disturbed area, and the direct topsoil replacement control variable enter into the selected forecasting equation, the combination of these three factors explain the labor impact on moving topsoil volumes rather than the actual topsoil moved

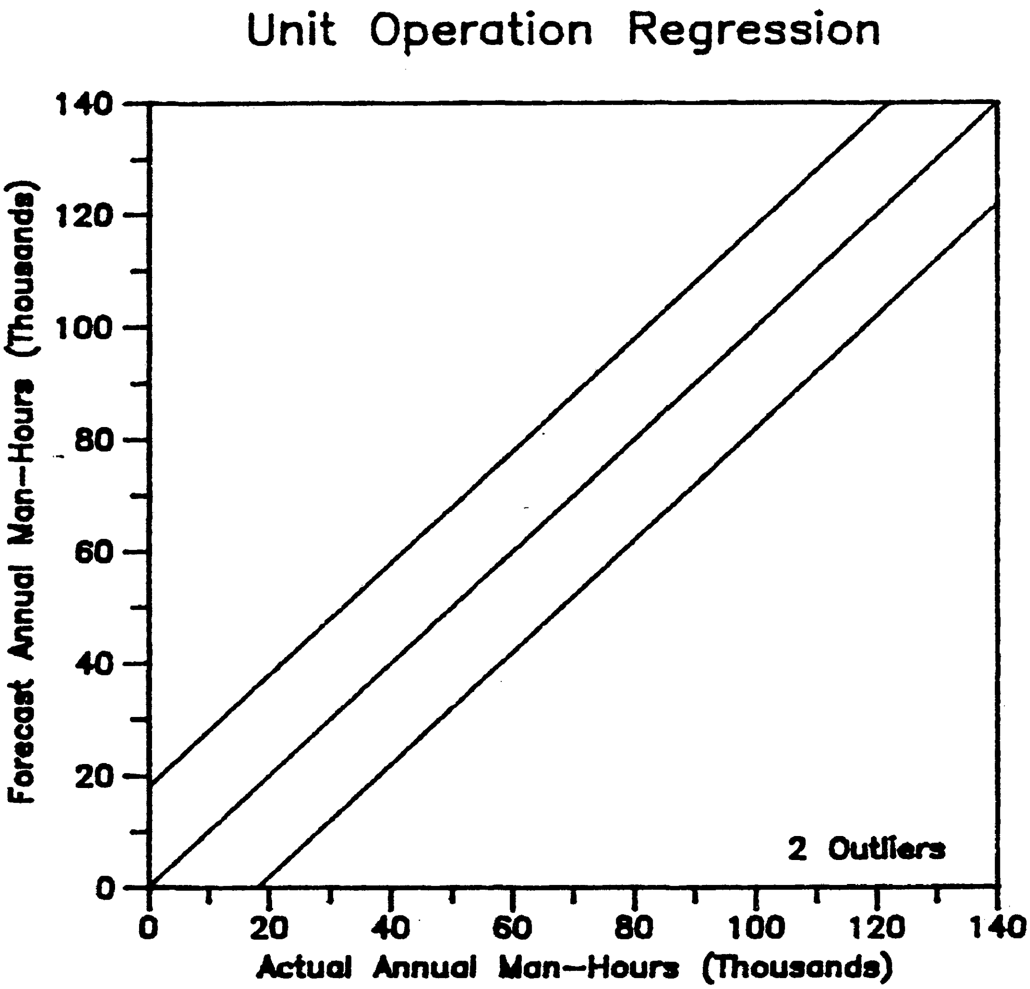


FIGURE 10. Forecast Versus Actual Man-Hours - Reclamation

reported by the mines. Perhaps the topsoil moved data was less accurate because some mines may not have included volumes of rehandled topsoil in the data.

The disturbed area factor may reflect the relationship of all three primary reclamation variables of spoil regrading, topsoil removal, and revegetation to the contribution of total reclamation man-hours. Since disturbed area basically describes the majority of reclamation activities, one would expect a large statistical significance as exhibited by the sizable t-statistic for the disturbed area coefficient (15.10 from Table 13). The other two factors, topsoil thickness and direct topsoil replacement, contribute additional reclamation man-hours associated with the volume of topsoil removed and the amount of the topsoil which is directly respread after removal, respectively.

Due to the interdependence of each factor on the reclamation process and differing physical dimensions, the regressed coefficients of the variables are not easily compared. It is interesting however that the coefficient of the direct replacement variable (15,591 man-hours) depicts the average quantity of man-hours required to stockpile topsoil per year rather than directly replacing it on the other side of the mined pit. The coefficient shows that it is advantageous on a labor productivity basis to practice direct respreading whenever possible.

Pit geometry factors do not statistically enter into the man-hour expression since there is very little variation in the mine data for these factors. In addition, these factors may be less significant due to the use of pre-stripping techniques like shovel/truck which require smaller quantities of material to be regraded.

Reasons For Unaccounted Regression Variation

Reclamation practices required by state law vary among surface coal mines in the study. These differing regulations could be the cause for a large portion of the remaining variation in forecast reclamation man-hours. If the mines were separated by state and then regressed, the resulting forecasting equations could potentially be more accurate. However, there is a maximum of five mines in each state which is too few data points to produce a meaningful regression equation.

Other physical factors which could potentially describe additional amounts of variation are listed below.

- Reclamation regulations such as soil sampling pattern, topsoil segregation by land owner, soil horizon separation, bond release timing, etc.
- Use of spoil bridges to minimize topsoil hauling distances
- Existence of toxic overburden when it impedes reclamation performance
- Favorable or unfavorable growing conditions
- Drainage problems and heavy rainfall
- Spoil regrading techniques

Stripping Unit Operation Analysis

Stripping Definition

The stripping unit operation is defined in this study to include activities associated with drilling and blasting burden layers and extracting all overburden and interburden materials. Possible job classifications for this unit operation are listed below.

- Drill operator
- Driller helper
- Blaster
- Blasting foreman
- Dragline operator
- Dragline oiler
- Dragline groundman
- Shovel operator
- Shovel oiler
- Shovel groundman
- Bucketwheel operator
- Bucketwheel oiler
- Bucketwheel groundman
- Truck operator
- Heavy equipment operator
- Scraper operator
- Dozer operator
- Stripping foreman
- General labor

Regression Factors

Table 14 lists the quantitative factors utilized as potential regression variables to forecast man-hours used for stripping activities.

Primary Stripping Variables

Volumes stripped: One of the most important factors impacting labor requirements in the stripping unit operation is the volume of burden extracted. Since different types of stripping equipment have correspondingly different production rates and productivities when removing burden volumes, the burden has been separated by the type of

TABLE 14. STRIPPING VARIABLES

Coal production (tons)
Average overburden thickness (feet)
Average number of interburden layers
Average interburden thickness (feet)
Average burden thickness (feet)
Total burden stripped (CY)
Dragline BCY moved (bank material)
Dragline BCY moved (rehandle material)
Dragline BCY moved (all material)
Average weighted dragline bucket capacity (CY)
Inverse of average weighted dragline bucket capacity
Average number of dragline swings (bank material)
Average number of dragline swings (rehandle material)
Average number of dragline swings (all material)
Average dragline scheduled hours
Number of draglines
Total dragline bucket capacity (CY)
Shovel BCY moved (bank material)
Shovel BCY moved (rehandle material)
Shovel BCY moved (all material)
Average weighted shovel bucket capacity (CY)
Inverse of average weighted shovel bucket capacity
Average number of shovel swings (all material)
Average shovel scheduled hours
Number of shovels
Total shovel bucket capacity (CY)
Average weighted primary stripping capacity (CY)
Inverse of average weighted primary stripping capacity
Auxiliary BCY moved
Bucketwheel excavator (BWE) BCY moved
Dragline + BWE BCY moved (bank material)
Dragline + BWE BCY moved (all material)
Shovel + auxiliary BCY moved (all material)
Spoil angle (degrees)
Highwall angle (degrees)
Average linear feet of burden material drilled and blasted
Control Variable: 0 = Non-union, 1 = Union

equipment used for extraction.

Using the four primary equipment methods of dragline, shovel/truck, scraper/dozer, and bucketwheel and actual average bucket sizes for the mines in the study, Table 15 was produced to estimate the man-hours required per cubic yard moved (method productivity) for each method. These values should be close approximations of the volume factor coefficients if the factors are significant in the regression analysis of stripping. When the same bucket size is assumed, the method productivities should remain fairly constant and provide a linear relationship between man-hours expended and cubic yards moved for the different methods. Also, the line should pass through the origin since labor is not required when no material volume is moved.

Two other important points are provided from Table 15. First, the table is arranged in order of greatest method productivity with draglines being the most productive and followed by BWE, shovel/truck, and scraper/dozer. This relative productivity ranking should be maintained for a meaningful regression.

TABLE 15.
MAN-HOUR CONTRIBUTION FROM PRIMARY EARTH-MOVING EQUIPMENT

Machine/Fleet	Bucket Size CY(2)	# of Men per 8-hr Shift	Man-Hours per Shift	Sec per Cycle	Mech Avail	Avg BCY(1) Production per Shift	Man-Hours per MM BCY
Dragline	56	3	24	60	90%	20,160	1,190
BWE(3)	12	5	40	N/A	85%	21,760	1,838
Shovel/Truck	19	5	40	30	90%	13,680	2,924
Scraper/Dozer	34	1.5	12	400	90%	1,836	6,536

(1) Assumes material swell of 20%
(2) Bucket size adjusted for fill factor
(3) Production rate of approximately 3,200 BCY/Operating Hour

A second and more important concept from Table 15 is the dependence of productivity on bucket capacity. A 10 CY increase in the dragline bucket size corresponds to a reduction of 180 man-hours per million BCY moved. This change in productivity is considerable when trying to forecast man-hours at an operation with sizable quantities of overburden. Hence, number of machine cycles is also used in the regression to account for the bucket size as an application of Equation 5 derived in the "Equipment Capacity Influence on Productivity" section of the chapter entitled "GENERAL PRODUCTIVITY RELATIONSHIPS".

For draglines, separation of bank and rehandled materials is provided since each type of material has different productivities. When rehandling overburden is required at an operation, the swing angle is typically increased which reduces the overall dragline productivity based on yards of material moved. Thus, the man-hours per BCY should be lower for rehandle compared to bank material. However, a separation of rehandle and bank volumes is not required for shovel/truck systems since the average productivity remains constant for any type of volume moved for the method.

Material volumes were combined in the analysis when the extraction productivities in Table 15 were similar in scale. Dragline and BWE volumes were combined for the regression as well as shovel and auxiliary (scraper/dozer) volumes.

Drilling and Blasting: Since drilling and blasting production has been generally measured by the mining industry in linear feet drilled for blasting, this measure was utilized in the stripping regression analysis. Linear feet drilled should have a positive contribution to stripping man-hours and pass through the origin. The relation is also assumed to be fairly linear since the overburden densities for the sandstone and shale layers drilled by mines in the study are close to 3,800 pounds per virgin cubic yard.

Nine mines in the study possessed unconsolidated overburden and did not require blasting. As part of the regression analysis, these mines were separated to determine if a better fit could be achieved due to the different stripping methods and spoil problems confronted (Fish and Hrebar, 1987).

Stripping Regression and Equation Selection

A stepwise regression was performed on stripping man-hours utilizing all factors listed in Table 14 and including all strip mines in the study. Table 16 presents the resulting significant regression models. Since there were numerous acceptable forecasting models generated, the final equation was selected on the basis of having the most primary stripping factors which fit the general mining concepts stated above.

Case 12 (s = 13,930 man-hours) was selected as the forecast equation since a) all volume factors were significant and exhibited the correct slopes, b) the equation included the separation of dragline bank and dragline rehandle volumes, and c) the coefficients of the volume factors had the same method productivity ranking estimated by Table 15.

Regression statistics for Case 12 are exhibited in Table 17, with a summary list of the final regression factors shown below. Figure 11 presents the forecast versus actual man-hours plot and displays that the forecasting function closely fits the actual data.

Dragline + BWE BCY moved (bank material)
Dragline BCY moved (rehandle material)
Shovel BCY moved (all material)
Auxiliary BCY moved
Linear feet drilled
Union Work Force?

TABLE 16.
STEPWISE REGRESSION OF STRIPPING MAN-HOURS - ALL MINES

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Drag Bank BCY	(+)	0.0041	0.0038	0.00248	0.00175	0.00076	0.00079
T-STATISTIC		11.00	15.12	7.55	6.20	2.12	2.50
Shovel Total BCY	(+)		0.0148	0.0158	0.0093	0.0086	0.099
T-STATISTIC			5.36	8.19	4.63	5.47	6.67
Aux. Total BCY	(+)			0.0186	0.025	0.0245	0.0226
T-STATISTIC				4.77	8.04	10.01	9.84
Feet Drilled	(+)				0.063	0.065	0.044
T-STATISTIC					4.46	5.80	3.45
Drag Rehandle BCY	(+)					0.0053	0.0051
T-STATISTIC						3.51	3.88
Union? (1=yes)	(+)						14754
T-STATISTIC							2.43
Standard Deviation		61458	40329	27918	19766	15479	13636
R-Squared (%)		-	-	-	-	-	-

TABLE 16 (continued).
STEPWISE REGRESSION OF STRIPPING MAN-HOURS - ALL MINES

Factors/T-stat.	Theoretical Sign	Case 7	Case 8	Case 9	Case 10	Case 11	Case *12*
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Drag+BWE Bank BCY	(+)	0.00407	0.00377	0.0025	0.00179	0.00081	0.00081
T-STATISTIC		11.18	15.84	7.84	6.64	2.07	2.31
Shovel Total BCY	(+)		0.0149	0.0158	0.0093	0.0086	0.0098
T-STATISTIC			5.63	8.44	4.90	5.44	6.49
Aux. Total BCY	(+)			0.0178	0.0243	0.0244	0.0227
T-STATISTIC				4.64	8.06	9.80	9.62
Feet Drilled	(+)				0.063	0.065	0.046
T-STATISTIC					4.62	5.78	3.51
Drag Rehandle BCY	(+)					0.005	0.005
T-STATISTIC						3.08	3.42
Union? (1=yes)	(+)						14120
T-STATISTIC							2.28
Standard Deviation		60619	38647	27145	18862	15553	13930
R-Squared (%)		-	-	-	-	-	-

TABLE 16 (continued).
STEPWISE REGRESSION OF STRIPPING MAN-HOURS - ALL MINES

Factors/T-stat.	Theoretical Sign	Case 13	Case 14	Case 15	Case 16	Case 17
Constant	(0)	0	0	0	0	0
T-STATISTIC		-	-	-	-	-
Drag Bank Swings	(+)	0.262	0.184	0.139	0.126	0.153
T-STATISTIC		11.70	6.52	10.08	9.77	11.03
Aux Total BCY	(+)		0.0192	0.0237	0.0253	0.0227
T-STATISTIC			3.56	9.52	11.17	11.04
Shov Total Swings	(+)			0.236	0.185	0.201
T-STATISTIC				8.89	6.05	7.78
1/Shov CY Cap.	(+)				439311	456817
T-STATISTIC					2.60	3.26
1/OB CY Cap.	(+)					-628383
T-STATISTIC						-3.04
Standard Deviation		58264	46716	21098	18489	15309
R-Squared (%)		-	-	-	-	-

TABLE 16 (continued).
STEPWISE REGRESSION OF STRIPPING MAN-HOURS - ALL MINES

Factors/T-stat.	Theoretical Sign	Case 18	Case 19	Case 20	Case 21	Case 22	Case 23
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Drag Total Swings	(+)	0.22	1.58	0.119	0.109	0.128	0.122
T-STATISTIC		12.49	7.08	10.95	10.53	11.43	11.45
Aux Total BCY	(+)		0.0183	0.0231	0.0246	0.0225	0.0219
T-STATISTIC			3.57	9.85	11.43	11.23	11.73
Shov Total Swings	(+)			0.226	0.18	0.193	0.205
T-STATISTIC				9.03	6.28	7.74	8.66
1/Shov CY Cap.	(+)				404686	419334	343669
T-STATISTIC					2.53	3.07	2.62
1/OB CY Cap.	(+)					-538136	-811609
T-STATISTIC						-2.76	-3.62
Union? (1=yes)	(+)						15070
T-STATISTIC							2.04
Standard Deviation		55027	44088	19670	17353	14837	13631
R-Squared (%)		-	-	-	-	-	-

TABLE 17.
STRIPPING MAN-HOUR FORECASTING FUNCTION - ALL MINES

Factor definitions:

SMH	=	Man-hours required for stripping unit operation
DBB	=	Dragline + BWE (millions of bank BCY moved)
DRB	=	Dragline rehandle (millions of equivalent BCY moved)
ST	=	Shovel (millons of total BCY moved)
AUX	=	Auxiliary (millions of total BCY moved)
FD	=	Linear feet drilled in burden material (thousands)
U	=	Dummy variable to relate whether the operation is union or non-union, where: 0 = a non-union mine 1 = a union mine

Regression:

Predictor	Coefficient	Std. Dev.	T-Statistic
DBB	805.8	349.5	2.31
DRB	4967	1454	3.42
ST	9847	1517	6.49
AUX	22653	2355	9.82
FD	45.76	13.03	3.51
U	14120	6197	2.28

S (std.dev.) = 13,930

Equation:

SMH = 805.9(DBB) + 4,967(DRB) + 9,847(ST) + 22,653(AUX) + 45.76(FD)
+ 14,120(U)

Range of predictor RMH = +/- 22,915 man-hours (90% Confidence)

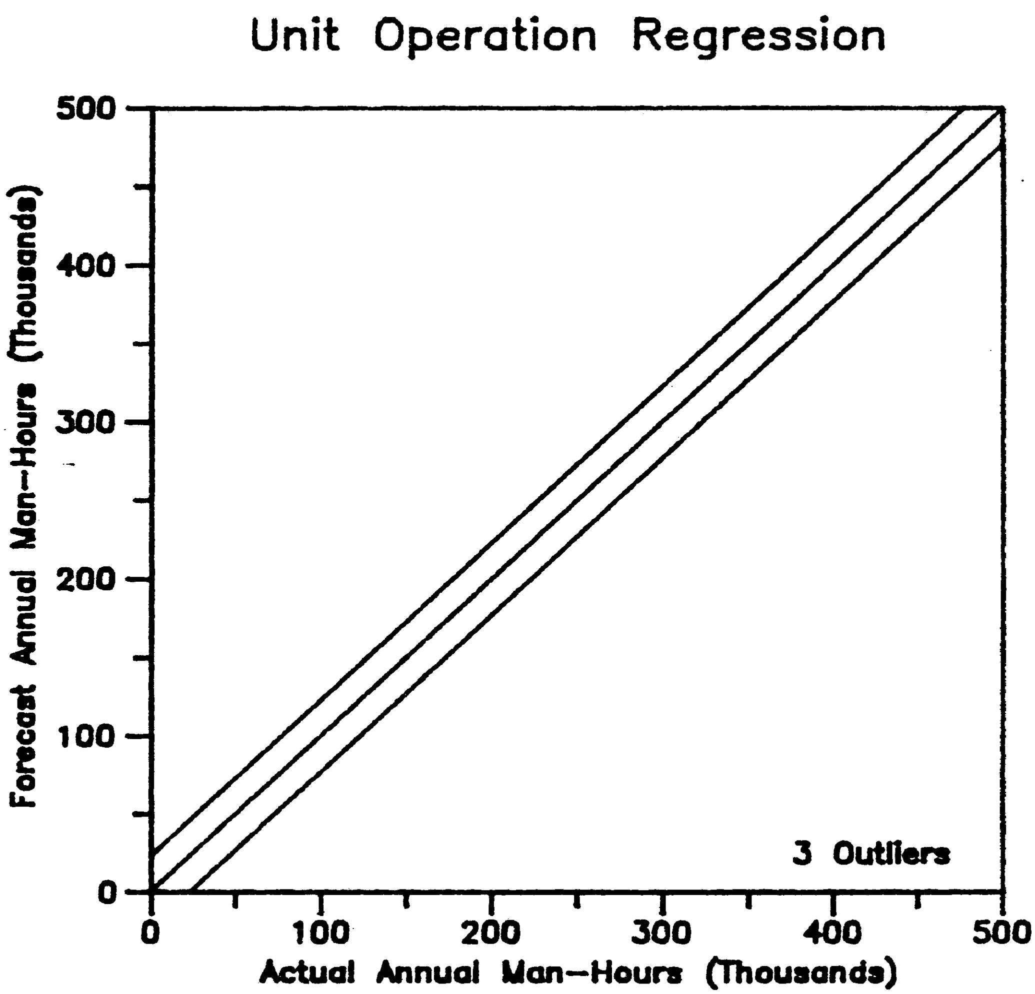


FIGURE 11. Forecast Versus Actual Man-Hours - Stripping (All Mines)

Tables 18 and 19 illustrate the models produced when the mines are grouped into those having overburden which require (consolidated) and do not require blasting (unconsolidated), respectively. The same selection criteria as for the regression of all mines were utilized to determine the forecasting equations for mines with different overburden consistencies. Case 9 from Table 18 (s = 12,012 man-hours) was used for the consolidated overburden mines and Case 6 from Table 19 (s = 16,934 man-hours) was used for the unconsolidated overburden mines. Regression statistics for the two cases are presented as Tables 20 and 21. The list below sets forth the resulting regression models selected for the two mine groups.

Unconsolidated Overburden	Consolidated Overburden
Dragline + BWE BCY (all mat'l)	Dragline BCY (bank mat'l)
Shovel + Auxiliary BCY	Dragline BCY (rehandle)
	Shovel + Auxiliary BCY
	Union work force?

Figures 12 and 13 represent the forecast versus actual man-hour plots for the two overburden types. In order to determine the best equation for the stripping unit operation, the squared value of the residuals for the two analyses were summed and then divided by the appropriate degrees of freedom. The resulting standardized deviations were very close, but the regression on all mines together has the least deviation and therefore used for the forecasting formula. The greater deviation from the separate regressions is primarily caused by the higher standard deviation of consolidated overburden mines since the drilling and blasting factor was not significant in the regression and shovel and auxiliary materials were not significant when regressed separately. When all of the mines were regressed together these important separations occurred.

TABLE 18.
STEPWISE REGRESSION OF STRIPPING MAN-HOURS - MINES WITH CONSOLIDATED OVERBURDEN

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Feet Drilled	(+)	0.178	0.14	0.044			
T-STATISTIC		14.41	10.17	1.32			
Shov+Aux Total BCY	(+)		0.00706	0.01092	0.01298	0.01305	
T-STATISTIC			3.55	5.55	10.59	12.15	
Dragline Total BCY	(+)			0.0022	0.00311	0.00254	
T-STATISTIC				3.04	13.29	7.46	
Union? (1=yes)	(+)					18555	
T-STATISTIC						2.09	
Dragline Bank BCY	(+)						0.00544
T-STATISTIC							7.1
Standard Deviation		30223	21544	16286	16821	14722	56730
R-Squared (%)		-	-	-	-	-	-

TABLE 18. (Continued)

Factors/T-stat.	Theoretical Sign	Case 7	Case 8	Case *9*
Constant	(0)	0	0	0
T-STATISTIC		-	-	-
Dragline Bank BCY	(+)	0.00366	0.00264	0.00144
T-STATISTIC		11.21	4.96	2.72
Shov+Aux Total BCY	(+)	0.01338	0.0128	0.01272
T-STATISTIC		9.4	10.29	14.36
Drag Rehandle BCY	(+)		0.0055	0.0069
T-STATISTIC			2.25	3.84
Union? (1=yes)	(+)			25387
T-STATISTIC				3.27
Standard Deviation		19707	16853	12012
R-Squared (%)		-	-	-

TABLE 19.
STEPWISE REGRESSION OF STRIPPING MAN-HOURS -
MINES WITH UNCONSOLIDATED OVERBURDEN

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3	Case 4	Case 5	Case *6*
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Aux Total BCY	(+)	0.0424	0.0267	0.0297			
T-STATISTIC		12.18	9.58	12.46			
Drag Rehandle BCY	(+)		0.008	0.0047			
T-STATISTIC			6.51	2.92			
Drag CY Cap.	(-)			344			
T-STATISTIC				2.58			
Shov+Aux Total BCY	(+)				0.0423	0.0248	0.0246
T-STATISTIC					12.21	8.12	8.95
Drag+BWE Bank BCY	(+)					0.00176	
T-STATISTIC						6.45	
Drag+BWE Total BCY	(+)						0.00149
T-STATISTIC							7.26
Standard Deviation		46328	18643	13877	46235	18769	16934
R-Squared (%)		-	-	-	-	-	-

TABLE 19. (Continued)

Factors/T-stat.	Theoretical Sign	Case 7
Constant	(0)	0
T-STATISTIC		-
Aux Total BCY	(+)	0.024
T-STATISTIC		8.80
Drag Bank Swings	(+)	0.136
T-STATISTIC		7.52
Standard Deviation		16432
R-Squared (%)		-

TABLE 20.
STRIPPING MAN-HOUR FORECASTIN FUNCTION -
MINES WITH CONSOLIDATED OVERBURDEN

Factor definitions:

SMH = Man-hours required for stripping unit operation
DB = Dragline (millions of bank BCY moved)
DRB = Dragline rehandle (millions of equivalent BCY moved)
SAT = Shovel + Auxiliary (millions of total BCY moved)
U = Dummy variable to relate whether the operation is union or non-union, where:
0 = a non-union mine
1 = a union mine

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
DB	1437.2	529.3	2.72
DRB	6900	1797	3.84
SAT	12724.2	886.3	14.36
U	25387	7766	3.27

S (std.dev.) = 12,012

Equation:

SMH = 1,437.2(DB) + 6,900(DRB) + 12,724.2(SAT) + 25,387(U)
Range of predictor RMH = +/- 19,760 man-hours (90% Confidence)

TABLE 21.
STRIPPING MAN-HOUR FORECASTING FUNCTION - MINES WITH UNCONSOLIDATED OVERBURDEN

Factor definitions:

SMH = Man-hours required for stripping unit operation
DBB = Dragline + BWE (millions of total bank BCY moved)
SAT = Shovel + Auxiliary (millions of total BCY moved)

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
DBB	1489.3	205.3	7.26
SAT	24623	2750	8.95

S (std.dev.) = 16,934

Equation:

SMH = 1489.3(DBB) + 24,623(SAT)
Range of predictor RMH = +/- 27,856 man-hours (90% Confidence)

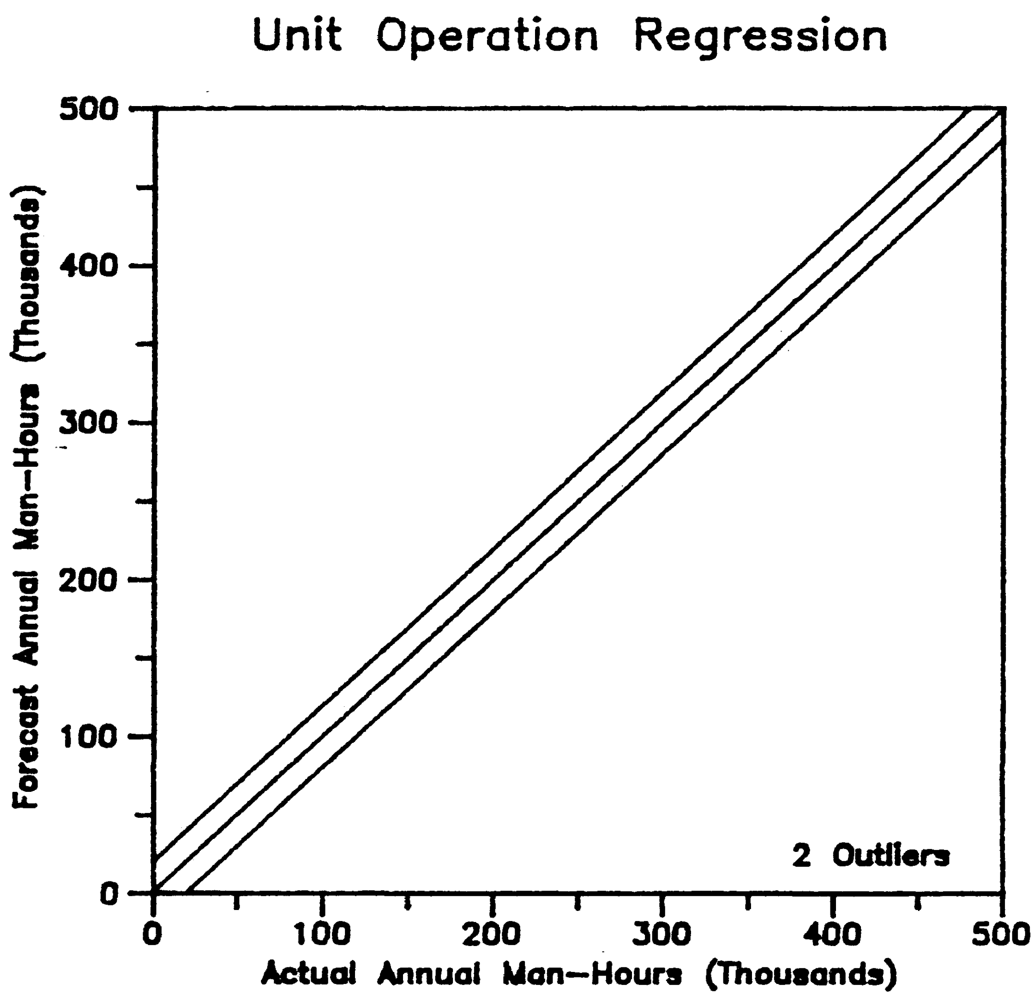


FIGURE 12. Forecast Versus Actual Man-Hours - Stripping (Mines With Consolidated Overburden)

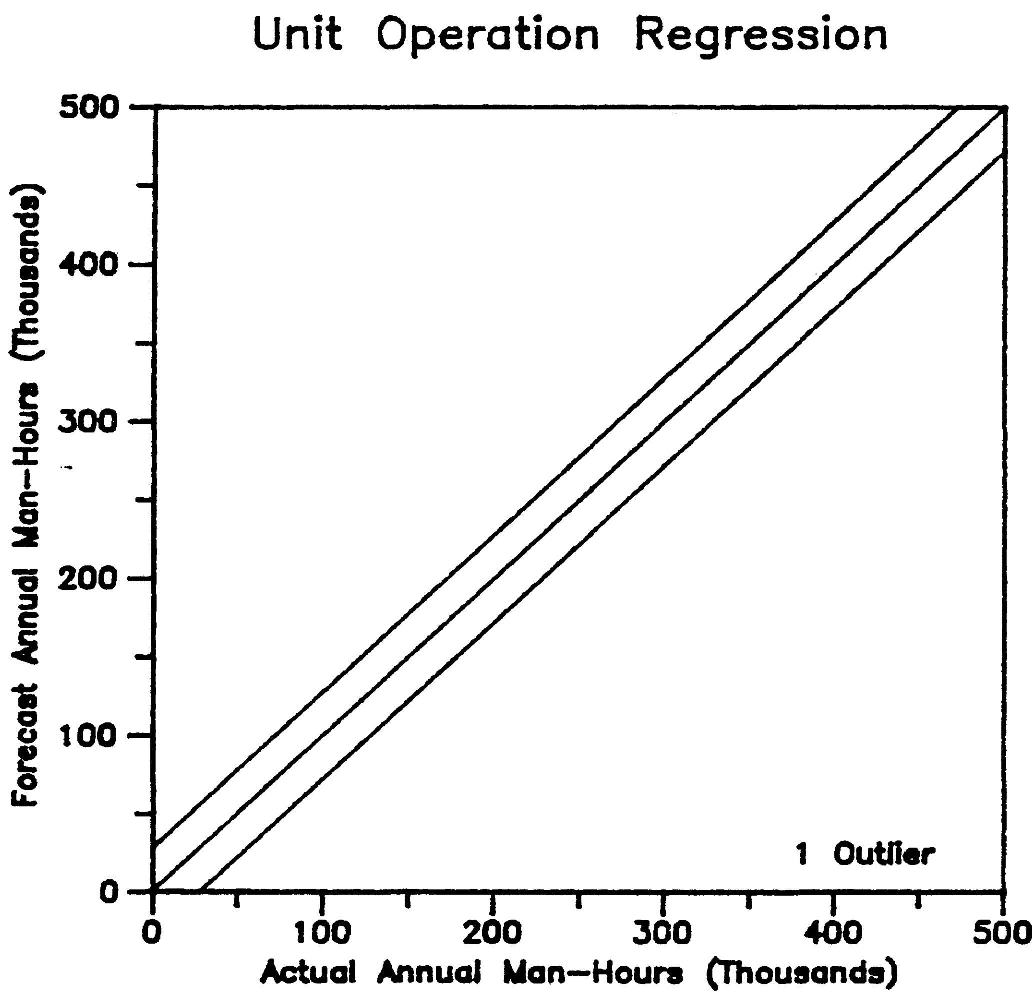


FIGURE 13. Forecast Versus Actual Man-Hours - Stripping (Mines With Unconsolidated Overburden)

Stripping Factor Analysis

The coefficients of the volume factors which represent the method productivities (man-hours per BCY) in the stripping forecasting equation were ranked in the same order as those predicted in Table 15. The estimated values in Table 15 did not include other manpower associated with extraction process and thus all of the values were correspondingly lower than the regression coefficients. The dragline bank material coefficient could be high since the bucketwheel production of one mine was combined with dragline bank volumes.

The regressed dragline rehandle coefficient of 4,967 man-hours/mm BCY was six times greater than that of the bank material, 806 man-hours/mm BCY, yet smaller than any other volume factor coefficient. Although it requires roughly one-half less manpower to move dragline rehandle material than it does for the shovel/truck system, the cost of moving dragline rehandle material can become so prohibitive that shovel/truck prestripping becomes competitive (Learmont, 1983). Since costs are not considered in the labor productivities, one must be careful when comparing man-hours per million BCY moved for different stripping systems.

The shovel/truck system productivity (9,847 man-hours/mm BCY) is 2.3 times better than auxiliary stripping methods (22,653 man-hours/mm BCY). On the basis of labor productivity, shovel/truck methods could be an attractive alternative to remove material when compared to scraper fleets.

Manpower from drilling and blasting activities are accounted for by the quantity of feet drilled. Nine of the mines did not have to drill their overburden which had a sizable effect of the quantity of man-hours required for stripping. From the regression coefficient an estimated average of 45.8 man-hours are required to drill and blast

1,000 feet of blasthole.

Unionization of the work force affected the unit operation by adding an average of 14,120 man-hours per year or roughly the equivalent of seven men. Most non-union operations employ less people in the stripping process because the labor force typically follows a technician system of requiring workers to perform many different jobs when necessary.

As presented in the "GENERAL PRODUCTIVITY RELATIONSHIPS" chapter, bucket capacity should have a large affect on the productivity of earth-moving activities, yet bucket capacity in the regression of stripping man-hours was not significant. In many cases the sign of the regressed coefficient was incorrect suggesting that bucket size was not critical in the contribution to stripping man-hours. Also, transposing bucket capacity into the number of machine swings (volume moved per cubic yard of bucket capacity) did not produce an appropriate forecasting equation.

The possible explanation of the insignificance of bucket size in the stripping unit operation might be the relationship between utilization or availability and the size of the machine. Since the effective bucket size is the direct combination of utilization and bucket size (see Equation 1 in "GENERAL PRODUCTIVITY RELATIONSHIPS"), and if there exists an inverse relation between the two factors, the effective bucket size could have only small variation and therefore not be significant in the regression analysis.

Reasons For Unaccounted Regression Variation

Remaining fluctuations in the forecast stripping man-hours may be described by the following additional factors.

- Differences in equipment utilization (deadheading, complex digging techniques, etc.)
- Differences in availability when crew is on machine
- Undersized dragline for stripping method
- Blastcasting (more preparation work required for blasting and bench preparation)
- Favorable or unfavorable swing angles
- Area mined (dragline bench preparation and cable movement)
- Spoil and highwall stability

Coal Loading Unit Operation Analysis

Coal Loading Definition

Activities associated in the coal loading process include cleaning the coal contact, fracturing the coal by blasting or ripping, and loading the coal into trucks. Possible job classifications for this unit operation are listed below.

- Scraper operator
- Dozer operator
- Motor grader operator
- Drill operator
- Driller helper
- Blaster
- Blasting foreman
- Front-end loader operator
- Shovel operator
- Backhoe operator
- E-Z miner operator
- General labor

Regression Factors

Table 22 below lists the quantitative factors used in the regression analysis of man-hours expended for coal loading activities.

Primary Coal Loading Variables

Coal Loading Into Trucks: As previously presented in Equation 4, the labor required for moving material is directly related to the volume to be moved divided by the bucket capacity of the machine, or more simply, the number of machine swings. This direct relationship can be utilized if the fixed times associated with the loading process such as truck spotting, face preparation, and moving time, are assumed to be small in comparison to the total cycle time. A labor productivity coefficient of 11.4 man-hours per 1,000 loader swings is estimated by using an average cycle time of 35

TABLE 22. COAL LOADING VARIABLES

Coal production (tons)
Number of coal seams
Total coal thickness (feet)
Average coal thickness (feet)
Average coal lift thickness (feet)
Inverse of average coal lift thickness
Number of coal loading machines
Total loader capacity (CY)
Average loader capacity (CY)
Average weighted loader capacity (CY)
Number of loaders swings
Coal haulage distance (feet)
Coal ton-miles
Acres of coal seam mined
Average linear feet of coal drilled and blasted
Acre-feet of coal mined
Control variable: 0 = No coal ripping, 1 = Coal is ripped

seconds, 85% machine availability, and one loader operator.

Since there is no data on the fixed component of the loader cycle, the analysis assumes minimal fixed times in the loader cycle. Taking into account this assumption, the plot of man-hours versus number of swings should have an increasing trend and pass through the origin. Linearity was assumed since the average cycle time will be fairly constant for most coal loading machines. However, as the coal seam thickness changes, variations in the cycle time may occur due to the ease of digging, bucket fill factor, and number of moves per loaded volume.

Coal Cleaning: Coal cleaning man-hours should be dependent on the area cleaned or the total acres of coal seam mined. The relation is assumed to have a positive linear slope and intersect the origin. The conditions of the seam contact with the overburden and bottom material should also have an effect on the labor required to clean the coal seam. No data on this factor was acquired and could not be entered into the regression analysis.

Coal Fragmentation: Fracturing the coal prior to removal is performed by drilling and blasting or by ripping the coal with dozers. The contribution of drilling and blasting the coal seam to unit operation man-hours, as with overburden, is related to the linear feet drilled. A positive linear relation should exist with man-hours including an intercept at zero.

A control variable is used in the analysis to see if ripping the coal seam was significant. A zero was used for mines with minimal coal ripping and a one for operations which used ripping as their primary method of coal fragmentation. If ripping activities impact coal loading manpower, ripping man-hours should be a function of the coal acres mined and the thickness of the coal seam since ripping is a multiple pass process with basically a constant fragmentation depth per pass.

Coal Loading Regression and Equation Selection

A stepwise regression was performed on coal loading man-hours utilizing all factors listed in Table 22. The regression models describing a significant portion of variation in man-hours are presented in Table 23. Coal acres mined and number of loader swings were the only factors determined to have significance in the regression.

Each of the two coal loading factors had the correct theoretical sign and behaved as suggested. The assumed linear relationship is justified since the residuals from the regression were found to have no recognizable trend. Case 2 in Table 23 was selected to forecast total coal loading man-hours with a standard deviation of 13,497 man-hours.

TABLE 23.
STEPWISE REGRESSION OF COAL LOADING MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case *2*
Constant	(0)	0	0
T-STATISTIC		-	-
Coal Acres Mined	(+)	96.9	64.7
T-STATISTIC		15.05	3.82
Drag Rehandle BCY	(+)		0.053
T-STATISTIC			2.03
Standard Deviation		14471	13497
R-Squared (%)		-	-

Table 24 presents the regression statistics for Case 2. The result of plotting forecast man-hours versus the actual man-hours and a confidence window of 90% is exhibited as Figure 14. The range of the 90% confidence indicates that there remains a sizable variation in coal loading man-hours not described by coal acres mined and loader swings.

Coal Loading Factor Analysis

Coal acres mined is the most significant factor in the regression with a t-statistic of 3.82. Coal acres takes into account seam interface cleaning, coal fragmentation, and possibly a portion of the coal loading process. Labor for drilling and blasting the coal seam might be a function of coal acres since there was only small variations in coal blasting patterns and the cycle time could be less dependent on the coal thick-

TABLE 24.
COAL LOADING MAN-HOUR FORECASTING FUNCTION

Factor definitions:
CLMH = Man-hours required for coal loading unit operation
CAM = Total acres of coal seam mined
LC = Number of loader cycles (thousands)

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
CAM	64.65	16.94	3.82
LC	52.88	25.99	2.03

S (std.dev.) = 13,497

Equation:
CLMH = 64.65(CAM) + 52.88(LC)
Range of predictor CLMH = +/- 22,203 man-hours (90% Confidence)

ness.

The inferred number of loader cycles also enters into the forecasting function. This factor relates the equipment size to loading productivity and shows the economy of scale in the coal mining process. Because coal thickness does not show significance in the regression model, it can be assumed that the problems encountered with thin seams are alleviated by the selection of faster and more maneuverable loading equipment.

The coefficients of the regressed coal loading factors provide useful information. First, an average of 65 man-hours are required to prepare one acre of coal for mining. This productivity measure may include some contribution from the loading process but is predominately associated with seam preparation and coal fragmentation.

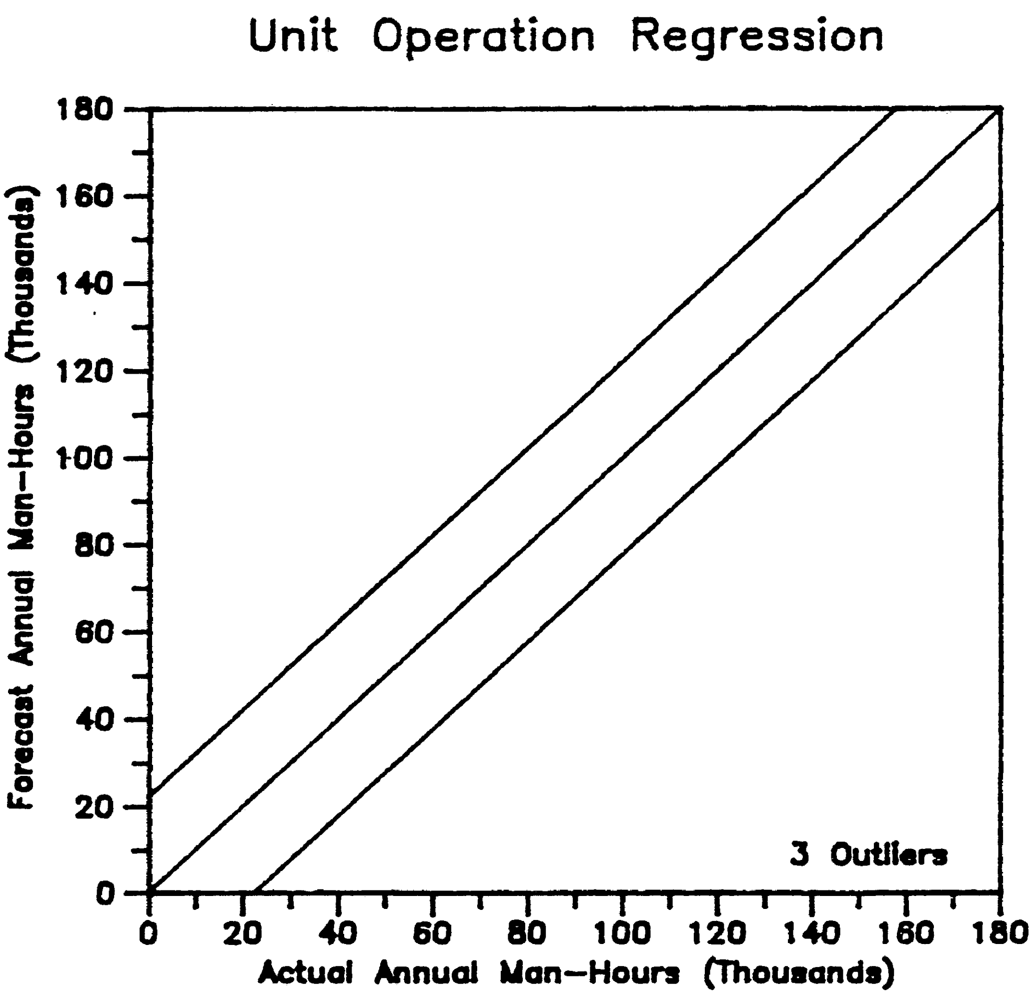


FIGURE 14. Forecast Versus Actual Man-Hours - Coal Loading

Another useful productivity measure is the 53 man-hours per 1,000 loader cycles value attained from the coefficient of number of loader cycles. This value is almost five times as high as the hypothesized value of 11.4 man-hours per 1,000 loader cycles since the regressed value includes fixed times and job delays.

Reasons For Unaccounted Regression Variation

After regression, fluctuations remained in the forecast coal loading man-hours suggesting there may be other physical factors which describe additional amounts of variation. Several possible factors are listed below.

- Use of continuous mining machines (several operations utilized the E-Z miner for which an equivalent bucket size was approximated)
- Number of loading places
- Coal hardness
- Blending requirements

Coal Hauling Unit Operation Analysis

Coal Hauling Definition

Coal hauling operations are defined to include all activities which provide transport of mined coal from the pit to a dumping point for further processing or loadout. Truck operator is the only possible job classification for this unit operation since road repair and truck maintenance are provided in other unit operations.

Regression Factors

The quantitative factors listed in the table below are believed to influence the quantity of man-hours used for coal hauling activities and were used in the regression analysis of coal hauling man-hours.

TABLE 25. COAL HAULING VARIABLES

Coal production (tons)
Haulage distance (feet)
Coal ton-miles
Truck load capacity (tons)
Number of truck loaded
Truck-miles
Average weighted coal loader capacity (CY)
Inverse of average weighted loader capacity
Number of loader swings

Primary Coal Hauling Variables

An empirical formula can be derived from the physical characteristics of coal truck cycling at an operation to determine the man-hours expended to haul coal production. The basic concept of the coal haulage formula is that the cycle time of one coal hauler consists of three basic parts: truck loading time, hauling time loaded and empty, and other fixed time. The equation for estimating the required man-hours for each of these time segments is formulated below.

Variables:			
	MH	=	Man-hours required to meet coal hauling requirements
	d	=	Haulage distance
	s	=	Average speed of truck (loaded and empty)
	C	=	Coal production (tons)
	TC	=	Truck capacity (tons)
	f	=	Fixed cycle times (dumping, spotting, job delays, etc)
	LC	=	Loader capacity (CY)
	CYC	=	Time for one loader swing cycle
	N	=	Number of truck loads required to meet coal requirements
	kx	=	Constants
	Kx	=	Constants

$$MH = N \times (\text{load time} + \text{haul time} + \text{fixed time})$$

$$N = C/TC$$
$$\text{Load Time} = k1 \times (TC/LC) \times CYC$$
$$\text{Haul Time} = k2 \times (2d/s)$$
$$\text{Fixed Time} = k3 \times f$$

$$MH = (C/TC) \times (k1 \times (TC/LC) \times CYC + k2 \times (2d/s) + k3 \times f) \qquad \text{(EQ. 6)}$$

Assuming that average truck speed is constant, fixed times are small relative to overall cycle period, and average loader cycle is constant, the equation simplifies to:

$$MH \sim Kl \times (C/LC) + Kh \times (Cd/TC) \qquad \text{(EQ. 7)}$$

As defined in Equation 7 above, the loading time is approximated by the number of swings necessary for the coal loader to fill the truck while the haulage time is estimated by the number of cycles each truck is required to make. Truck dumping time is considered to be negligible. These two transformed factors, (C/LC) and (Cd/TC), should explain the majority of variation in the coal hauling man-hour data. Each factor will have a positive trend with man-hours and intersect the origin. The assumption of linearity can be asserted since there are only linear terms in the empirical relationship.

Coal Hauling Regression and Equation Selection

A stepwise regression was performed on coal hauling man-hours using all basic and transformed factors. Table 26 presents all regression models describing a significant portion of variation in man-hours.

TABLE 26.
STEPWISE REGRESSION OF COAL HAULING MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Constant	(0/+)	0	0	0	0	-13010	37307
T-STATISTIC		-	-	-	-	-1.32	1.97
Truck Loads	(+)	1.37	2.00				
T-STATISTIC		9.37	9.29				
Loader CY Cap.	(-)		-1758				
T-STATISTIC			-3.51				
Loader Swings	(+)			1188	2407	1375	
T-STATISTIC				11.55	6.27	7.90	
Coal Tons Moved	(+)				-0.0115		1511
T-STATISTIC					-3.26		9.78
Truck Ton Cap.	(-)						-463
T-STATISTIC							-2.97
Standard Deviation		32555	26249	27331	22636	26862	22783
R-Squared (%)		-	-	-	-	75.70	83.41

The two derived factors for Equation 7, number of loader swings and truck-miles, are significant in the regression and exhibited characteristics consistent with the

TABLE 26. (Continued)

Factors/T-stat.	Theoretical Sign	Case *7*
Constant	(0)	0
T-STATISTIC		-
Loader Swings	(+)	0.149
T-STATISTIC		3.78
Truck-Miles	(+)	0.145
T-STATISTIC		1.87
Standard Deviation		25848
R-Squared (%)		-

empirical relation. Thus, Case 7 in Table 26 was selected to forecast total man-hours. Table 27 presents the regression statistics for the selected model which has a standard deviation of 25,848 man-hours.

The result of plotting forecast man-hours versus the actual man-hours is presented as Figure 15. Residual analysis however does not confirm the assumption that the factors have a linear relation with man-hours. Most forecast man-hours are above the actual man-hours expended at the mines until approximately 80,000 coal hauling man-hours. Above 80,000 man-hours all mines are predicted to have less man-hours than reality. The bias in the forecasting function indicates a trend which is not linear.

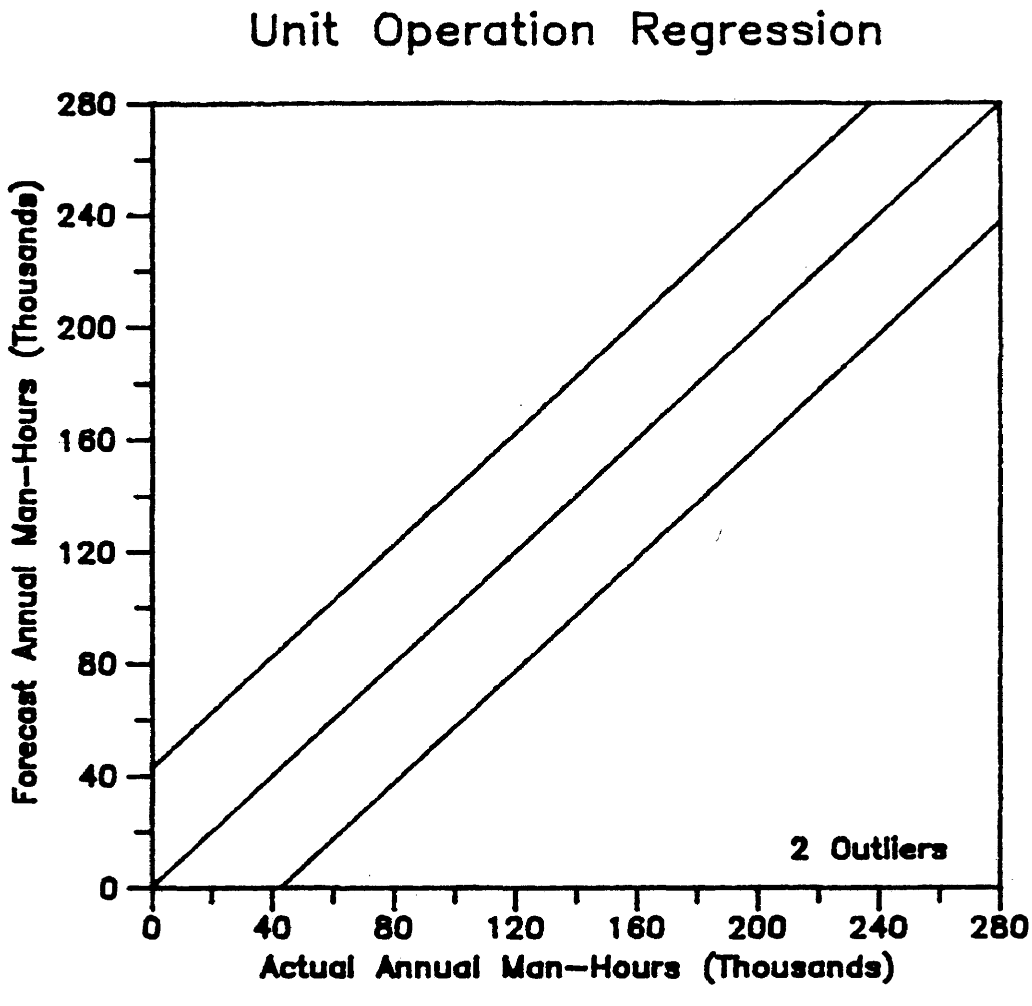


FIGURE 15. Forecast Versus Actual Man-Hours - Coal Hauling

TABLE 27.
COAL HAULING MAN-HOUR FORECASTING FUNCTION

Factor definitions:
CHMH= Man-hours required for coal hauling unit operation
TM = Truck-miles (thousands)
LC = Number of loader cycles (thousands)

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
TM	145.02	77.74	1.87
LC	149.43	39.57	3.78

S (std.dev.) = 25,848

Equation:
CHMH = 145.02(TM) + 149.43(LC)
Range of predictor CHMH = +/- 42,520 man-hours (90% Confidence)

Coal Hauling Factor Analysis

The regression analysis conforms to the theoretical relationship between coal hauling man-hours and the two transformed factors derived in Equation 7. Both factors are significant in the regression, although the truck-miles factor has a t-statistic of 1.87 which is slightly above the minimum statistically significant t-statistic of 1.72 for 21 degrees of freedom.

The standard deviation of 25,848 man-hours is the largest deviation of the unit operations analyzed so far and the regression residuals indicate that there is a non-linear term either in or not included in the forecasting function. These two regression problems imply that the fixed times in the truck or loader cycle might be more significant than assumed. The non-linear variation could also be explained by other assumptions in the theoretical relationship not being accurate.

Coefficients of the regression factors indicate an average of 145 man-hours are required to transport coal for 1,000 truck-miles and approximately 149 man-hours are expended per 1,000 loader swings. Since the coefficients are almost equal, it follows that the time for to complete one truck-mile is approximately equal to one loader swing. If one assumes a conservative 45 seconds for one loader cycle, a truck must travel one mile in 45 seconds, or at a speed of 80 miles per hour. This relationship between the coefficients is obviously questionable and should only be used for the mathematical forecasting of man-hours.

Reasons For Unaccounted Regression Variation

Since the regression left large fluctuations in the forecast man-hours, it is obvious that are other factors which describe additional amounts of variation. Several of these factors are listed below.

- Factors previously assumed to be constant such as truck speed, hauler cycle time, and loader cycle time
- Haul profile
- Dumping mechanism (end dump or bottom dump) which affects dumping time
- Haul road condition
- Weather conditions

Coal Preparation & Loadout Unit Operation Analysis

Activities pertaining to coal preparation and loadout begin at the coal hauler dumping point and can extend directly to feeding coal into a power plant. Although the 23 mines in the study possessed many different methods of coal product preparation and loadout, the mines can be grouped into the following five categories:

- Crush coal only
- Crush coal and rail loadout
- Crush coal and rail to plant
- Crush coal and convey to plant
- Crush coal, convey, and rail loadout

The manpower requirement for each of the above classifications displays a parallel increasing trend with coal production. Figure 16 attempts to subjectively fit parallel trend lines to the five preparation and loadout categories in order to make a rough approximation of unit operation man-hours. Windows showing 90% confidence are not included since regression techniques were not utilized.

Other more detailed manpower estimating techniques can be used for this unit operation if desired. The actual labor requirements vary too much for a meaningful regression to be achieved with the data in the study since preparation and loadout labor is entirely dependent on the type of market to be served. Preparation and loadout man-hours will not be used in the summation of unit operation man-hours.

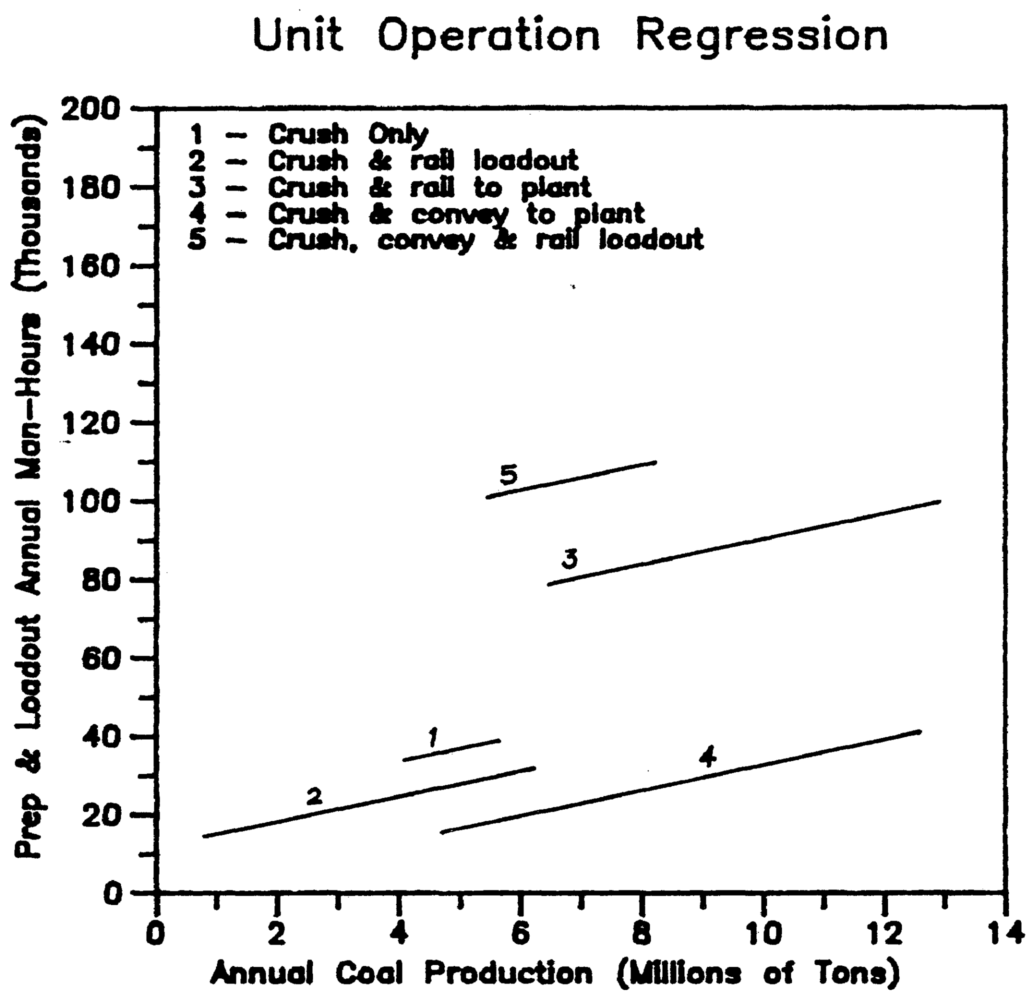


FIGURE 16. Actual Man-Hours Versus Coal Production - Preparation & Loadout

Maintenance Unit Operation Analysis

Maintenance Definition

Manpower required for the repair and maintenance of all equipment and facilities is included in this unit operation. Excluded from the maintenance labor are oilers which are typically an integral part of the operation of large machines like draglines and shovels. Possible job classifications for the maintenance unit operation are listed below.

- Mechanics
- Electricians
- Welders
- Maintenance foreman
- Maintenance supervisor
- General labor

Regression Factors

The table below lists the factors used in the stepwise regression analysis and believed to potentially influence the manpower requirements for maintenance operations.

TABLE 28. MAINTENANCE VARIABLES

Coal production (tons)
Total tons of material moved (coal and burden)
Total equipment bucket capacity (CY)
Number of primary earth-moving machines
Total mine man-hours
Production man-hours (all manpower except G&A and Maintenance)
Mechanical availability (%)
Mine age
Control Variable: 0 = non-union, 1 = union

Primary Maintenance Variables

Since the quantity of maintenance labor is largely dependent on the mining company's maintenance philosophy and the quantity and complexity of the equipment utilized in the operation, a primary maintenance factor is difficult to initially determine. The factor which should prove to have the most impact on maintenance man-hours is expected to be the number of man-hours worked by production employees or more specifically those involved in reclamation, stripping, coal loading and hauling, preparation and loadout, and mine support activities. Production man-hours generally project the number of machines utilized and the time they are operated at the mine. If there is no production manpower, there should be little maintenance required. As the production man-hours increases, the equipment is used more and maintenance should increase in approximately a constant fashion.

From conversations with mine operators, it is widely accepted that a ratio of maintenance to production manpower, commonly known as the maintenance ratio, in the range of 65 to 80 percent is the optimal point where the marginal maintenance cost is approximately equal to the benefits in production cost from enhanced mechanical availability. This ratio is generally thought to be constant in relation to mine size.

Figure 17 presents the range of the actual maintenance ratio against size of the operation or total mine man-hours less G&A man-hours. The graph illustrates that the ratio is not constant at the mine average of 71 percent, but ranges from a low of 20 percent to a high of 90 percent. This large range in the maintenance ratio contradicts the assumption of a linear relation between maintenance and production manpower. Figure 18 presents the plot of maintenance annual man-hours versus production annual man-hours for the mines in the study. This graph also exhibits a non-linear

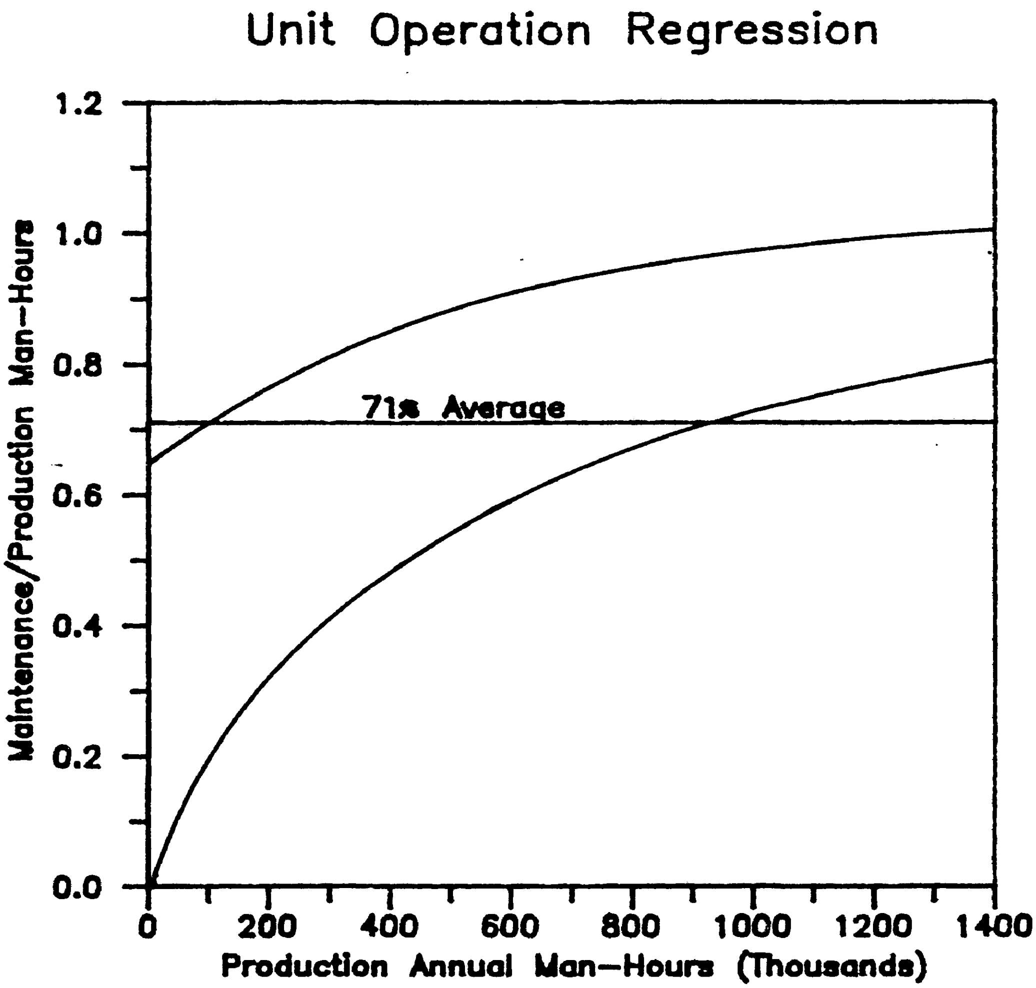


FIGURE 17. Maintenance Ratio Versus Actual Production Man-Hours

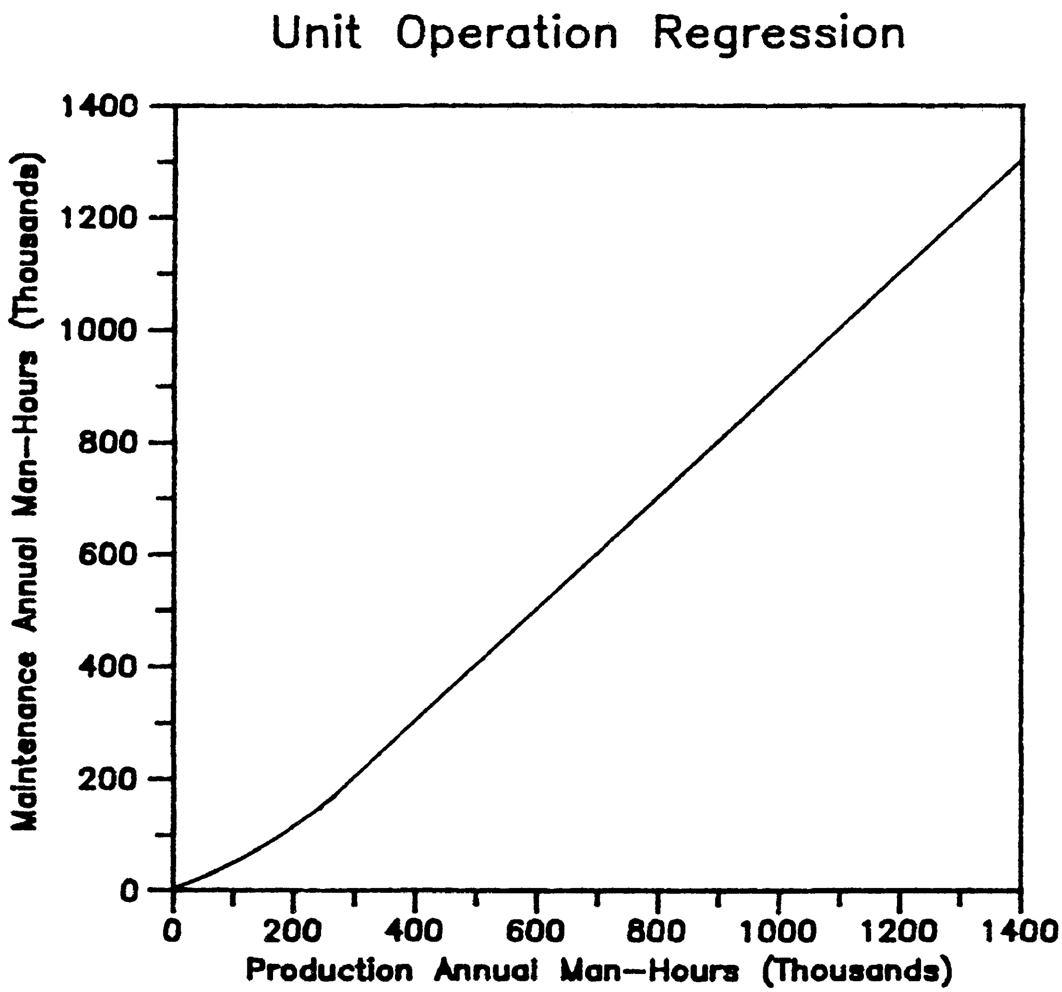


FIGURE 18. Actual Maintenance Man-Hours Versus Actual Production Man-Hours

trend, especially for the smaller operations.

Maintenance Regression and Equation Selection

A stepwise regression was performed on maintenance man-hours utilizing the factors listed in Table 28. The resulting regression models describing a significant portion of variation in maintenance labor requirements are displayed in Table 29. Significance was determined to only exist with the production man-hours factor.

Case 1 was considered to be an unrealistic model since the negative intercept allowed negative maintenance man-hours for small operations. In order to have a positive intercept, the maintenance ratio must actually increase as the production man-power increases. Therefore, production man-hours was transformed by the logarithm

TABLE 29.
STEPWISE REGRESSION OF MAINTENANCE MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case *3*
Constant	(0/+)	-35541	0	0
T-STATISTIC		-3.57	-	-
Prod Man-hours	(+)	0.736	0.714	
T-STATISTIC		10.26	24.64	
Prod Man-hours$^{(1)}$	(+)			0.03517
T-STATISTIC				34.95
Standard Deviation		44169	57632	40983
R-Squared (%)		85.39	-	-

(1) Production Man-hours raised to the 1.2238 power.

function as shown in Table 30, resulting in the production man-hours factor being raised to the power of 1.2238 to approximate the non-linear relationship.

Case 3 in Table 29 provides for the transformation and is selected to forecast maintenance manpower. Table 31 presents the statistics for the regression which possessed a standard deviation of 40,983 man-hours. The result of plotting forecast maintenance man-hours versus the actual man-hours is presented as Figure 19 and the data points exhibit no residual trend.

Maintenance Factor Analysis

An increasing maintenance ratio with operation size was projected by transforming production man-hours. Although not consistent with the mining industry's

TABLE 30.
MAINTENANCE TRANSFORMATION

Factor definitions:
LMMH = Log of man-hours required for maintenance unit operation
LTPMH = Log of production man-hour
C = Regression constant

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
C	-3.387	1.245	-2.72
LTPMH	1.2238	0.09987	12.25

R^2 = 0.882
S (std.dev.) = 0.3406

Equation:
LMMH = -3.387 + 1.2238(LTPMH)
Range of predictor LMMH = +/- 0.560 (90% Confidence)

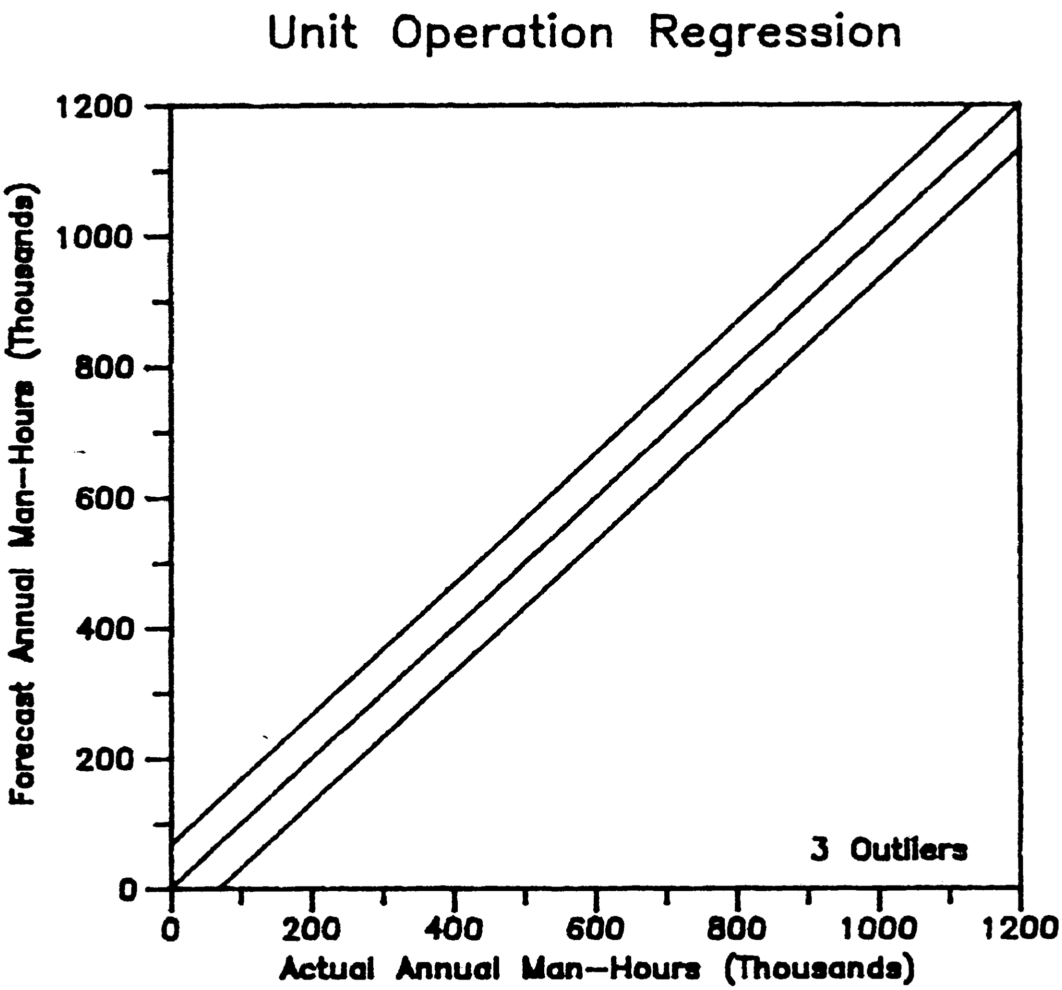


FIGURE 19. Forecast Versus Actual Man-Hours - Maintenance

TABLE 31.
MAINTENANCE MAN-HOUR FORECASTING FUNCTION

Factor definitions:
MMH = Man-hours for maintenance unit operation
TPMH = Production man-hours raised to the 1.2238 power

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
TPMH	0.035174	0.001006	34.95

S (std.dev.) = 40,983

Equation:
MMH = 0.035174(TPMH)
Range of predictor MMH = +/- 67,417 man-hours (90% Confidence)

optimal and primarily constant maintenance ratio of 65-80%, the coal mine data indicates that there is significance in the non-linear relationship.

Two possible reasons could explain the varying maintenance ratio. First, equipment operators at smaller mines might be allowed or perhaps encouraged to maintain their own equipment. This would decrease the official maintenance department and spread maintenance and repair responsibilities among the different unit operations. Several small operations were observed to practice this method.

A second reason might be the actual procedure for accounting maintenance man-hours. One operation had to be excluded from the unit operations analysis since the majority of man-hours from equipment repair was charged to the machine and not to the maintenance department. Other mines might have utilized this system when filling out the MPA data sheets from which this analysis was based.

Nonetheless, the dramatic variation in the maintenance ratio causes concern. If a smaller mine is using the generally accepted industry ratios, maintenance labor could be reduced without a significant decrease in equipment and facility utilization.

Reasons For Unaccounted Regression Variation

Other potential reasons for fluctuations in the forecast man-hours are suggested below.

- Complex equipment or facilities
- Use of prototype equipment
- Differences in repair time for hydraulic versus electrical equipment
- Use of different makes of equipment versus all from the same manufacturer
- Fleet age

Mine Support Unit Operation Analysis

Mine Support Definition

This unit operation includes all direct mining activities which do not fit the unit operations previously defined. The majority of mine support labor is derived from road maintenance, pit water pumping, ash disposal for power plants, and construction projects. Job classifications which could possibly be assigned to this unit operation are listed below.

- Grader operator
- Dozer operator
- Water truck operators
- Pumpers
- Truck operators
- General labor

Regression Factors

The factors listed below were used in the stepwise regression of mine support man-hours.

TABLE 32. MINE SUPPORT VARIABLES

Coal production (tons)
Total material moved (tons)
Haulage distance (feet)
Coal ton-miles hauled
Mine age (years)
Number of active roads
Water pumped per day (gallons/day)
Coal hauling man-hours
Other production man-hours (total man-hours less G&A and mine support)

Primary Mine Support Variables

Road Maintenance: Road maintenance man-hours should be directly related to the quantity of time that the roads are being used for coal haulage. Hence, there could potentially be a road maintenance ratio which would define the percentage of road building and repair labor required per coal hauling man-hour. The ratio should be basically constant producing a linear relationship between road maintenance man-hours and hauling man-hours. The relation should also pass through the origin.

Many highway departments and county systems charge truck haulage on a ton-mile basis in order to recover road maintenance costs. This possible relationship was also examined in the mine support regression analysis.

Water pumping: Pumping requirements for a mine, measured in gallons of water pumped per day, will increase the man-hours required for mine support. It is also reasonable to assume that when pumping is not necessary, no man-hours will be expended.

Other Factors: Due to the numerous sources contributing to mine support man-hours, other factors were not able to be quantitatively defined with the data in this study.

Mine Support Regression and Equation Selection

Table 33 presents the models which successfully describe a significant portion of variation in mine support man-hours derived from the stepwise regression of the factors listed in Table 32. Hauling man-hours and water pumped per day were the only factors to have significance in the stepwise regression analysis. Table 34 presents the regression statistics for the Case 2 model which resulted in a standard deviation of 15,728 man-hours. Both factors possess the correct sign and no discernible trend in the regression residuals was evident.

Forecast versus the actual man-hours is presented as Figure 20. The wide band of variation in the forecast is expected because of the unquantifible factors which

TABLE 33.
STEPWISE REGRESSION OF MINE SUPPORT MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case *2*
Constant	(0/+)	0	0
T-STATISTIC		-	-
Haul Man-hours	(+)	0.8346	0.99271
T-STATISTIC		15.95	9.25
Water Per Day	(+)		0.01076
T-STATISTIC			2.18
Standard Deviation		17778	15728
R-Squared (%)		-	-

TABLE 34.
MINE SUPPORT MAN-HOUR FORECASTING FUNCTION

Factor definitions:
MSMH= Man-hours required for mine support unit operation
CHMH= Coal hauling man-hours
H2O = Water pumped for the pit per day (gallons/day)

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
CHMH	0.92271	0.09974	9.25
H2O	0.01076	0.00493	2.18

S (std.dev.) = 15,728

Equation:
MSMH = 0.92271(CHMH) + 0.01076(H2O)
Range of predictor MSMH = +/- 25,873 man-hours (90% Confidence)

enter into mine support activities. It is believed that even with these unknown factors a good correlation is achieved with the coal hauling labor and water pumping factors.

Mine Support Factor Analysis

The coefficient of the hauling man-hours factor relates the average number of road maintenance man-hours required per hour man-hour of coal haulage. The coefficient value of 0.92 indicates an average road repair ratio of 92% for the mines in the study or approximately one road maintenance man-hour for each coal hauling man-hour. This ratio appears to be slightly high, although several mine's visited used a ratio of roughly 0.45 graders per haul truck. When additional labor for road activities such as road building and dust suppression are added, the road maintenance ratio might get as high as the 0.92 ratio achieved from regression.

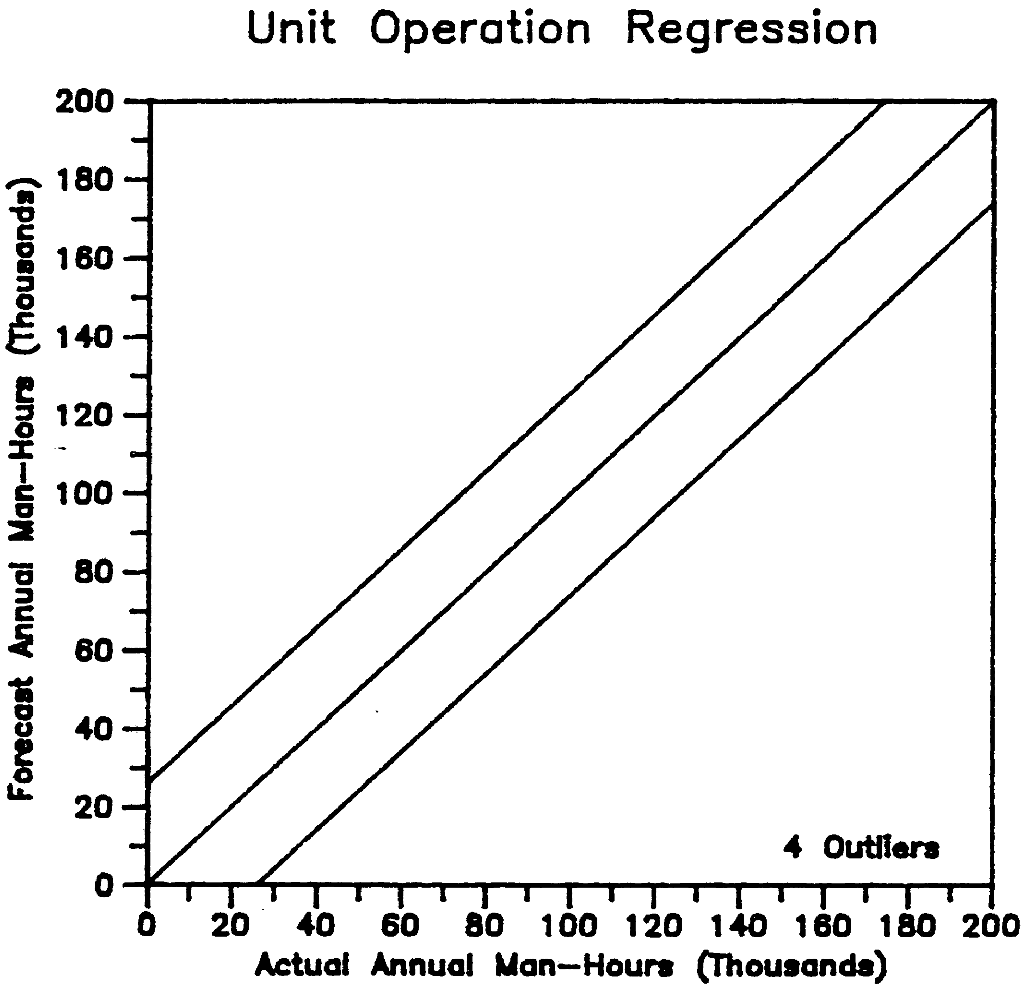


FIGURE 20. Forecast Versus Actual Man-Hours - Mine Support

Water pumped per day was also a significant factor in the computation of mine support labor. The factor's coefficient predicts that an average of 10.8 annual man-hours will be utilized to pump every interval of 1,000 gallons of water per day. If an operation has very difficult pit water problems, this factor could impact the overall mine productivity.

Reasons For Unaccounted Regression Variation

The remaining fluctuations in the forecast mine support man-hours might be explained by other physical factors. Several of these additional factors are listed below.

- Number of layers in road base building
- Weather conditions
- Steep topography
- Ash disposal
- Construction projects
- Use of on-highway coal trucks

General & Administrative Unit Operation Analysis

General & Administrative Definition

The general & administrative (G&A) operation encompasses all duties performed by personnel not directly involved in the process of coal production. These duties include:

- Mine management and officers
- Mine supervision crossing more than one unit operation
- Engineering
- Surveying
- Accounting
- Personnel
- Marketing
- Clerical
- Payroll
- Safety
- Purchasing
- Sample testing laboratory
- Warehouse

Regression Factors

The table below lists the factors which could potentially influence the quantity of man-hours used for G&A purposes.

TABLE 35. GENERAL & ADMINISTRATIVE VARIABLES

Coal production (tons)
Total production (tons)
Total man-hours
Mine man-hours (total man-hours less G&A)
Number of coal seams
Overburden thickness
Total interburden thickness
Total burden thickness
Control Variable: 0 = non-union, 1 = union

Primary G&A Variables

Operation Complexity: Complex stripping techniques have a sizable impact on the labor required to design and implement day-to-day mining plans, to survey coal and overburden volumes, and to supervise the operations. With an increase in the the number of coal seams encountered, the labor necessary to perform these duties also increases. It is difficult to predict if the relationship will be linear, but it can be assumed that the result will be an increasing trend in man-hours.

Operation Size: The size of the operation is expected to be a major determinant in G&A man-hours. Operation size can be related to the coal production or total production with the latter including both coal and overburden tons moved.

Many duties in the G&A operation such as marketing, coal sampling, and accounting are more a function of the product and not activities unrelated to coal production. However, other G&A activities are related to the entire mining process such as purchasing and distributing mining supplies. Even though it is difficult to project which factor will be more significant, one of these two production quantities should enter into the analysis and have a positive slope through the origin.

Personnel Support: A sizable organizational structure must be developed to support the activities of any mining operation. The organization will assist the mining process by providing management, supervision, payroll, safety awareness, and other personnel duties. Since these responsibilities are dependent on the number of employees at the mine, one of the primary G&A factors should include total number of man-hours spent at the mine.

As the total number of employees rises, the personnel support should also rise to take care of the needs of the work force. Again it seems reasonable that there should be a constant ratio of personnel support for a given number of employees or employee man-hours.

G&A Regression and Equation Selection

G&A man-hours are regressed using the stepwise procedure, with all significant regression models displayed in Table 36. The forecasting formula in Case 3 is selected because it includes all of the critical G&A factors and it behaves linearly. Table 37 presents the regression statistics for Case 3 with a standard deviation of 44,600 man-hours.

TABLE 36.
STEPWISE REGRESSION OF G&A MAN-HOURS

Factors/T-stat.	Theoretical Sign	Case 1	Case 2	Case *3*	Case 4	Case 5	Case 6
Constant	(0)	0	0	0	0	0	0
T-STATISTIC		-	-	-	-	-	-
Total Man-hours	(+)	0.0193	0.153	0.092			
T-STATISTIC		13.25	8.97	3.29			
No. of Seams	(+)		19694	17771		22336	20098
T-STATISTIC			3.30	3.34		3.56	3.54
Coal Prod.	(+)			0.0103	0.0278	0.0213	0.0133
T-STATISTIC				2.59	11.79	8.15	3.29
Mine Man-hours (1)	(+)						0.082
T-STATISTIC							2.46
Standard Deviation		61320	50548	44600	67987	54481	48675
R-Squared (%)		-	-	-	-	-	-

(1) Equal to total man-hours for the mine less G&A man-hours.

TABLE 36. (Continued)

Factors/T-stat.	Theoretical Sign	Case 7	Case 8
Constant	(0)	53667	88300
T-STATISTIC		3.01	4.19
Total Man-hours	(+)	0.146	0.155
T-STATISTIC		7.35	8.60
Union? (1=yes)	(+)		-56833
T-STATISTIC			-2.50
Standard Deviation		52149	46408
R-Squared (%)		73.00	79.70

(1) Equal to total man-hours for the mine less G&A man-hours.

TABLE 37.
G&A MAN-HOUR FORECASTING FUNCTION

Factor definitions:

GAMH= Man-hours required for mine support unit operation
TMH = Total operation man-hours
NOS = Average number of coal seams mined per pit
CP = Coal production (millions of tons)

Regression:

Predictor	Coefficient	Std.Dev.	T-Statistic
TMH	0.09182	0.02788	3.29
NOS	17771	5314	3.34
CP	10298	3981	2.59

S (std.dev.) = 44,600

Equation:

GAMH = 0.09182(TMH) + 17,771(NOS) + 10,298(CP)
Range of predictor MSMH = +/- 73,367 man-hours (90% Confidence)

Forecast man-hours versus actual man-hours for the G&A unit operation is presented as Figure 21. The G&A factors appear to predict man-hours quite well for smaller operations. As the G&A man-hours reach approximately 125,000 annual man-hours however, the residuals increase substantially. Linearity is still justified since the residuals do not trend in one direction.

G&A Factor Analysis

The variables expected to be primary factors in G&A man-hours are significant in the forecasting equation. However, the appearance of coal production rather than total tons moved may suggest that a portion of G&A manpower is more dominated by coal related activities.

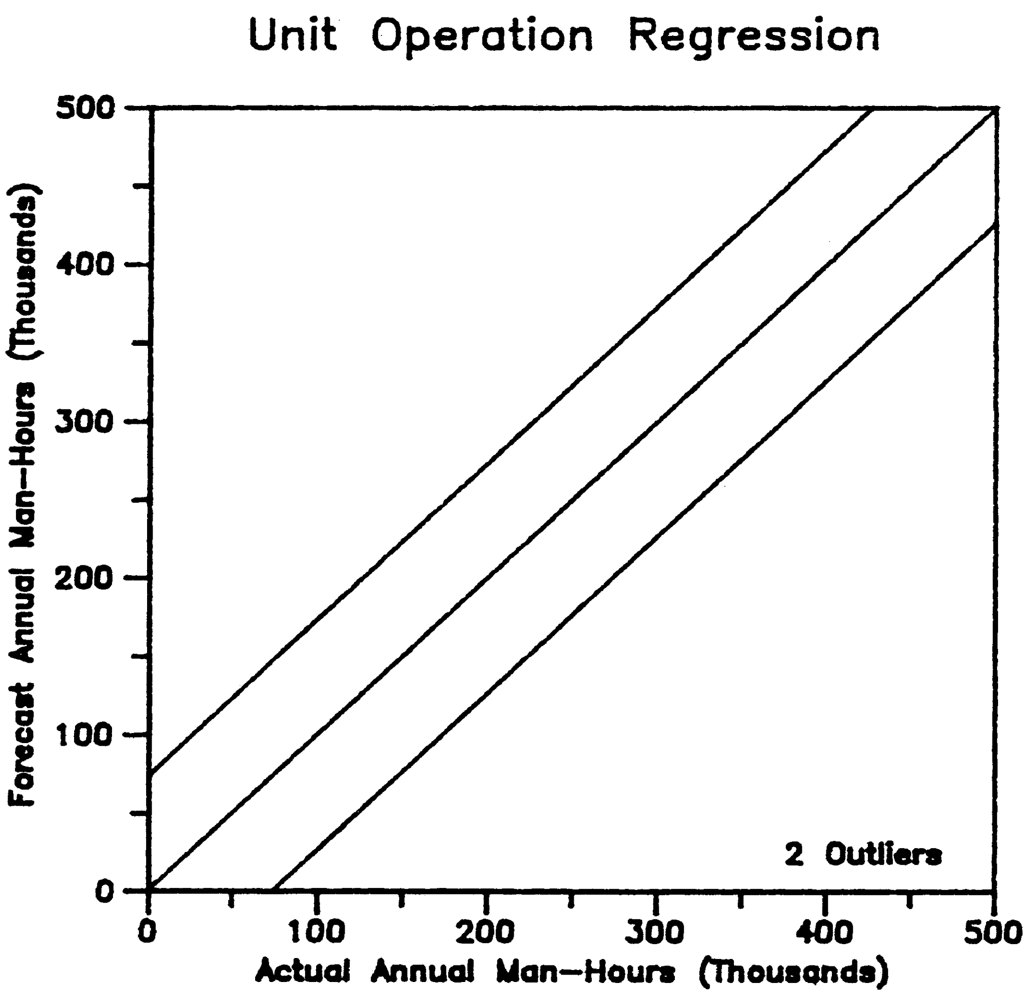


FIGURE 21. Forecast Versus Actual Man-Hours - G&A

The regression coefficients again provide useful information. An average of 17,800 man-hours of engineering and surveying, or roughly 9 people, are required annually for each coal seam recovered. This value is expected not to be entirely constant since design and monitoring procedures will be very similar for operations with many seams. For every one million tons of coal production per year approximately 10,300 man-hours or about five men will be used to administrate of the operation. In addition, an average of 9.2 percent of the total man-hours at the operation (including G&A) is needed to support the mine employees.

Reasons For Unaccounted Regression Variation

Since the regression left some fluctuations in the forecast man-hours, other physical factors may describe additional amounts of variation. Several additional factors are presented below.

- Management style (corporate or entrepreneurial)
- Coal market and production security
- Type of labor force

Method Application

Application of the unit operation forecasting model is very similar to that of the overall productivity function except there is a man-hour forecasting equation for each unit operation and the overall productivity must be calculated from known coal production. Applying the forecasting method begins by inputing the appropriate factor values into each unit operation's equation and computing the estimated man-hours. The unit operation man-hours are then summed to yield an estimated annual manpower requirement for the mine with productivity computed by dividing coal production by the forecast man-hours. A more thorough procedure for forecasting labor productivity at one mine is outlined below.

STEP 1

Determine or approximate the following values:

DA = Newly disturbed area for topsoiling operations (acres)
TT = Topsoil thickness (inches)
DR = Control Variable: 0 = greater than 50% of topsoil is directly replaced,
1 = less than 50% of topsoil is directly replaced
DBB = Dragline + BWE million BCY moved (bank material)
DRB = Dragline million BCY moved (rehandle material)
ST = Shovel/Truck million BCY moved (all material)
AUX = Auxiliary million BCY moved
FD = Linear feet drilled in burden (thousands)
U = Control variable: 0 = non-union, 1 = union
CAM = Total acres of coal mined (all seams)
LC = Thousands of coal loader cycles (BCY coal/Loader CY capacity)
TM = Thousands of coal hauler miles
((Coal tons/truck tonnage capacity) x one-way miles hauled)
Mpl = Preparation and loadout man-hours estimated by Figure 16 or alternative methods
H20 = Average gallons of water pumped from the pit per day (thousands)
NOS = Average number of coal seams per pit
CP = Coal production (thousands of tons)

STEP 2

Calculate the unit operation man-hours (Mxx) using the above data values and the productivity functions which follow. Since several functions utilize the man-hours computed from prior functions, use the equations in the order presented.

Reclamation:
$Mr = 125.7(DA) + 274.3(TT) + 15{,}591(DR)$

Stripping:
$Ms = 806(DBB) + 4{,}967(DRB) + 9{,}847(ST) + 22{,}653(AUX) + 13.03(FD) + 14{,}120(U)$

Coal Loading:
$Mcl = 64.7(CAM) + 52.9(LC)$

Coal Hauling:
$Mch = 145.0(TM) + 149.4(LC)$

Preparation & Loadout
Mpl (see Figure 16 or supply an alternative method)

Mine Support:
$Mms = 0.92271(Mch) + 10.76(H20)$

Maintenance:
$Mm = 0.035174(Mr + Ms + Mcl + Mch + Mms)^{1.2238}$

G&A:
$Mga = (0.09182(Mr + Ms + Mcl + Mch + + Mpl + Mm + Mms) + 17{,}771(NOS) + 10.298(CP)) / (0.90808)$

STEP 3

Add all of the unit operation man-hour quantities to obtain the total man-hours for the mine.

Total Man-Hours:
$Mt = Mr + Ms + Mcl + Mch + + Mpl + Mm + Mms + Mga$

STEP 4

Taking the coal tons produced for the year and dividing it by the forecast total man-hours results in the estimated mine labor productivity. The accumulated standard deviations of the man-hour forecasting functions using a 90% confidence interval is 272,234 annual man-hours. This value when added and subtracted from the total man-hours will furnish an expected range for the derived labor productivity.

Method Conclusions

The unit operation regression analysis provides a more detailed understanding of the factors influencing productivity at the mine level. The method also provides a procedure to estimate the labor required to operate and manage a dragline mine.

Numerous meaningful labor ratios are supplied from the regression coefficients in the analysis. Mining operations can compare these average ratios with their actual ratio to evaluate the how their operation is performing relative to the mines in the study. As an example, the overburden extraction productivities in the stripping unit operation can provide a measure of the average labor required to strip overburden for different earth-moving equipment. A mine can compare their method productivities with the average to ascertain if their operation is as productive.

All unit operations with material movement are influenced by the capacity of the equipment with the exception of the stripping unit operation which was expected have the greatest dependence on bucket capacity. The insignificance of bucket capacity in the stripping process can not be explained.

A possible limitation to the unit operation method is the potential for mines to account unit operation man-hours in different ways. If this occurs, the results of the regression analysis could lack accuracy since unit operation man-hours are not consistent. It is believed however that these inaccuracies are minor and will primarily cancel out when summing all of the unit operations.

Figure 22 exhibits the forecast versus actual man-hours for the summation of all unit operations. The range of the 90% confidence window contains all of the data points since much of the variation in the unit operations canceled out. The variation is expanded in scale by taking the ratio of forecast to actual man-hours for each mine as displayed in Figure 23. This graph shows that the unit operation productivity method tends to forecast more man-hours than actually expended since 15 out of the 23 mines are estimated above the 1:1 line. Hence, the unit operation forecasting method tends to be conservative by biasing the total man-hours greater than reality. By random chance, the residuals of the man-hours for the seven unit operations being forecast add together rather than entirely canceling out.

Total productivity is computed without preparation & loadout with the result plotted in Figure 24. Most points fall in the region where productivity is forecast lower than reality.

The impact of each influential factor in the unit operation can be determined by computing the average quantity of man-hours that the factor contributes to the mining operation. This technique is used in Table 38 where the factor man-hours are calculated by using the average value of the factor at the 23 mines and multiplying by the factor's regression coefficient in the unit operation analysis. The same factors definitions are used as presented in the method application section.

The most influential factors in Table 38 have the greater individual percentages of the total man-hours. The factor with the most impact in the analysis is PMH, production man-hours, which contributes on average roughly 30 percent of the total mine man-hours associated with the maintenance unit operation. Table 39 presents the factors in descending order of influence on total mine manpower requirements. Some of

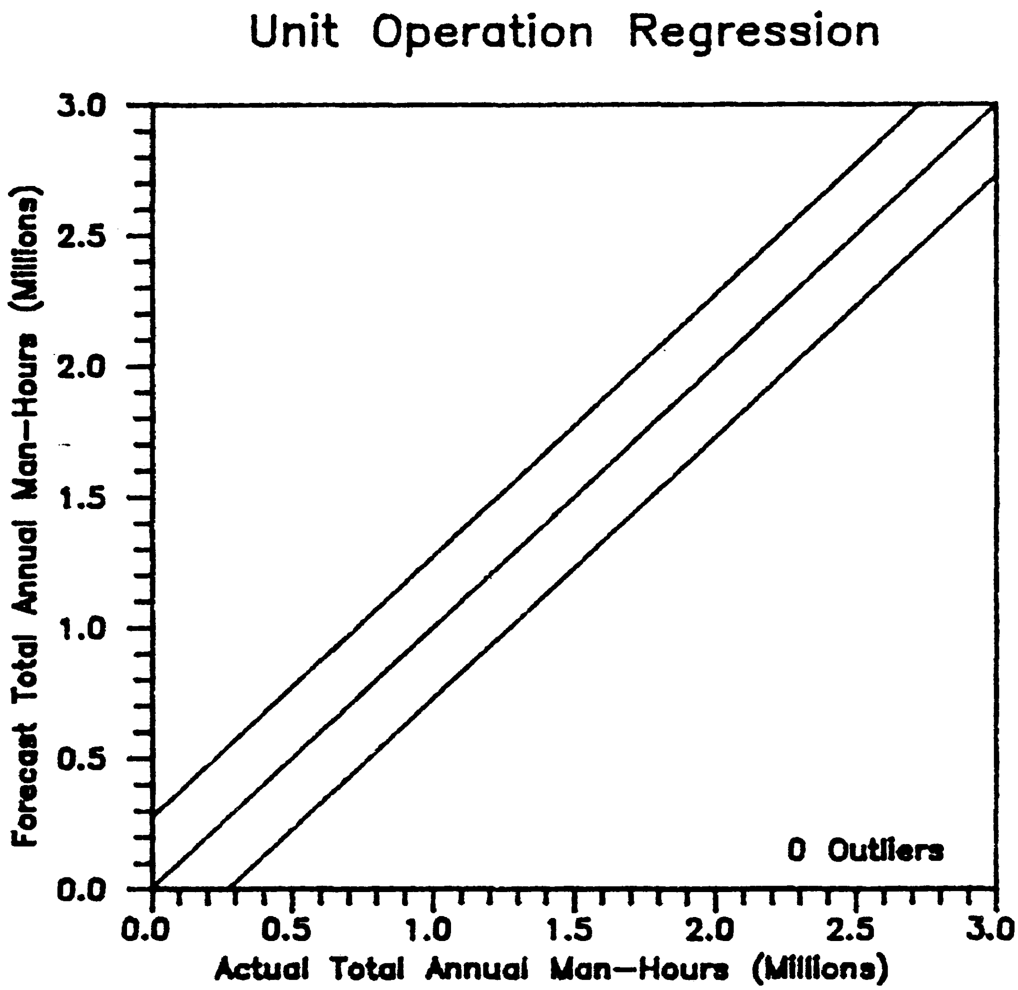


FIGURE 22. Total Forecast Versus Actual Man-Hours - Unit Operation Regression

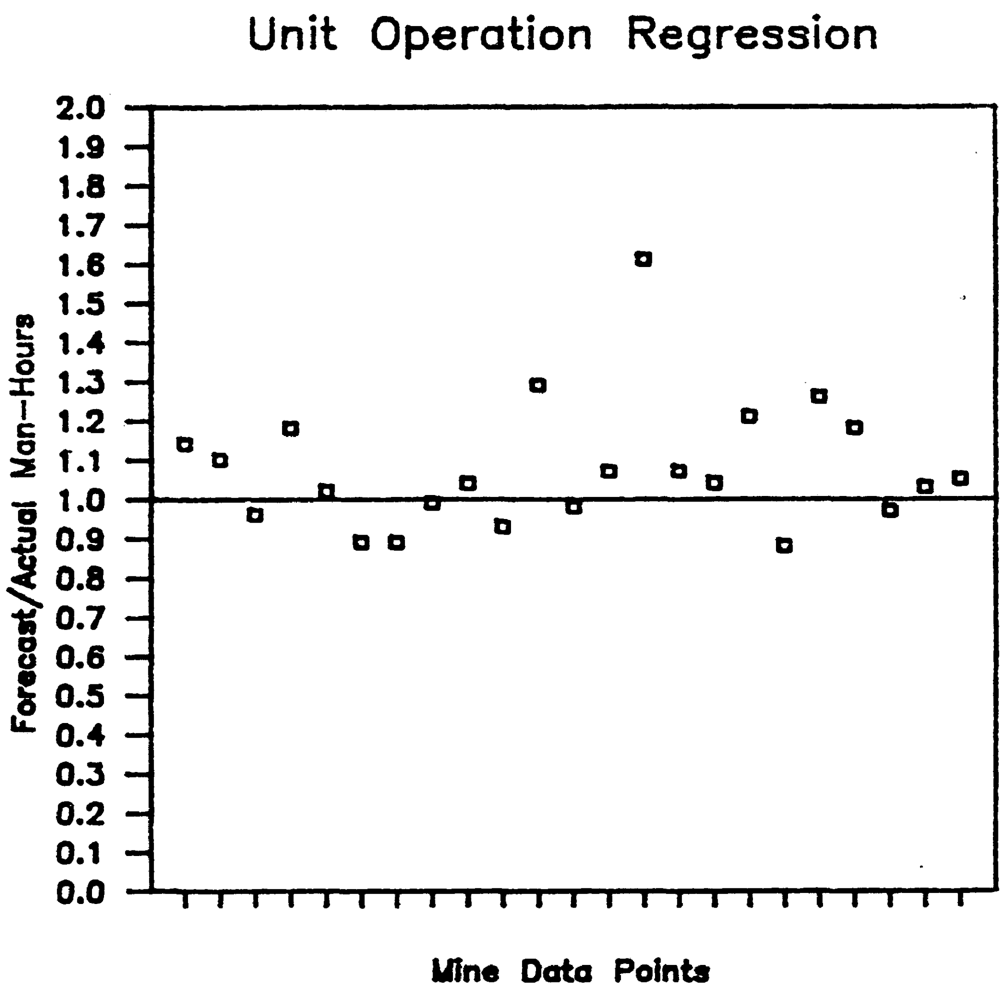


FIGURE 23. Total Forecast/Actual Man-Hours - Unit Operation Regression

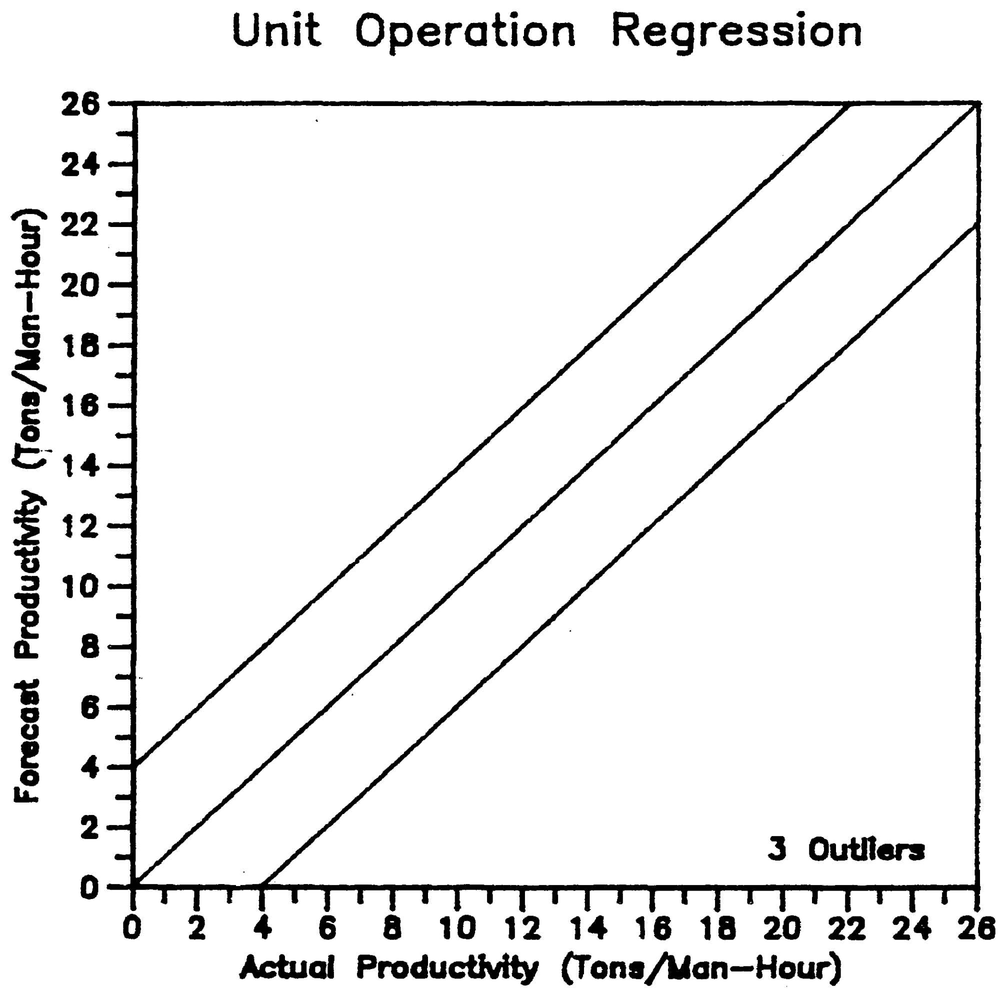


FIGURE 24. Forecast/Actual Productivity - Unit Operation Regression

TABLE 38. MAN-HOURS CONTRIBUTION BY UNIT OPERATION FACTORS

Factor	Actual Average Value	Regression Coefficient	Average Man-hours	Percentage of Unit Operation	Percentage of Mine Total
Reclamation:					
DA	264.7	125.7	33,273	70.6	4.55
TT	23.3	274.3	6,391	13.6	0.87
DR	0.478	15,591	7,452	15.8	1.02
RMH			47,116	100.0	6.45
Stripping:					
DBB	25.641	805.8	20,662	16.4	2.83
DRB	5.274	4,967	26,196	20.8	3.58
ST	2.230	9,847	21,959	17.4	3.00
AUX	1.312	22,653	29,721	23.5	4.07
OFD	389.4	45.76	17,819	14.1	2.44
U	0.696	14,120	9,828	7.8	1.34
SMH			126,185	100.0	17.26
Coal Loading:					
CAM	360.5	64.65	23,306	77.5	3.19
LC	259.7	25.99	6,750	22.5	0.92
CLMH			30,056	100.0	4.11
Coal Hauling:					
TM	128.6	145.0	18,647	32.5	2.55
LC	259.7	149.4	38,799	67.5	5.31
CHMH			57,446	100.0	7.86
Prep & Loadout:					
Actual Man-Hours			37,037	100.0	5.07
Maintenance:					
PMH	6,386,000	0.03517	224,596	100.0	30.73
MMH			224,596	100.0	30.73
Mine Support:					
CHMH	49,847	0.9227	45,994	93.7	6.29
H20	287,628	0.01076	3,095	6.3	0.42
MSMH			49,089	100.0	6.72
G&A:					
TMH	717,469	0.09182	65,878	41.3	9.01
NOS	2.22	17,771	39,452	24.8	5.40
CP	5.246	10,298	54,023	33.9	7.39
GAMH			159,353	100.0	21.80
Total			730,878		100.0

the factors presented in the table are not controllable since they are characteristics of the coal property and can not be changed in the short term. Thus, a mine should concentrate on manipulating the controllable factors to improve labor productivity, although the factors vary in the degree of control by the mine operator.

It was previously speculated that the accurate forecasting of unit operations with the largest quantity of man-hours should insure the success of the analysis. The fol-

TABLE 39. UNIT OPERATION FACTOR RANKING(1)

Unit Operation Factor	Associated Unit Operation	Controllable Factor?
Production man-hours	Maintenance	Yes
Total man-hours for the operation	G&A	Yes
Coal production	G&A	No
Coal hauling man-hours	Mine Support	Yes
Coal loader cycles	Coal Loading	Yes
	Coal Hauling	Yes
Average number of coal seams per pit	G&A	No
Newly disturbed area for topsoil	Reclamation	Yes
Auxiliary BCY moved	Stripping	Yes
Dragline rehandle BCY moved	Stripping	Yes
Total acres of coal mined	Coal Loading	No
Shovel/Truck total BCY moved	Stripping	Yes
Dragline + BWE bank BCY moved	Stripping	Yes
Coal hauler miles	Coal Hauling	Yes
Linear feet drilled in burden	Stripping	Yes
Union/non-union	Stripping	No
Direct respreading of topsoil	Reclamation	Yes
Topsoil thickness	Reclamation	No
Average gallons/day pumped from the pit	Mine Support	Yes

(1) Ranked in order of man-hour contribution

lowing table presents the relative size and regression coefficient for each unit operation.

TABLE 40.
UNIT OPERATION SIZE AND FORECASTING STANDARD DEVIATION

Unit Operation	Actual Percent of Total Man-hours	Forecast Percent of Total Man-hours	Standard Deviation, s
Maintenance	30.6	30.7	40,983
G & A	22.2	21.8	44,600
Stripping	16.6	17.3	13,930
Coal Hauling	7.2	7.9	25,848
Mine Support	6.8	6.7	15,728
Reclamation	6.4	6.4	10,906
Prep & Loadout	5.2	5.1	N/A
Coal Loading	5.0	4.1	13,497

Maintenance and G&A operations are the largest portion of man-hours and possess the greatest variation in the forecast. Since these unit operations are not primarily based on empirical relations, it is reasonable expect these deviations. Nonetheless, a major portion of the variation has been explained and the result forecast is concluded to be meaningful. In addition, the forecast percent of total man-hours is very close to the actual percentages.

COMPARISON OF PRODUCTIVITY FORECASTING METHODS

The preceding two chapters have presented and analyzed the two methods of predicting labor productivity, overall labor productivity regression and unit operation regression. A comparison of the methods based on the difference between the forecast and actual productivities of the mines in the study is exhibited in the table below. To compare the methods consistently, preparation and loadout man-hours have not been included in the calculation of productivity residuals.

TABLE 41. COMPARISON OF THE PRODUCTIVITY FORECASTING METHODS

	Overall Productivity Regression	Unit Operation Regression
Sum of Residuals	0.00	14.221
$(\text{Sum of Residuals})^2$	56.765	68.543
Degrees of Freedom	23 - 4 = 19	23 - 19 = 4
Residual Deviation	2.99	17.1

On the basis of residual deviation, the overall productivity regression function forecasts reality with less error. One would initially suspect that the unit operation productivity function would forecast productivity with greater accuracy since each activity in the mining process was studied in detail. However, the affect of the degrees of freedom and the biased residuals promotes the larger residual deviation for the unit operation method. It is expected that with more detailed data and further analysis the unit operation method will produce a more accurate result.

CONCLUSIONS

Productivity has sometimes been referred to as a measure of ignorance since there is only a certain part of productivity that is explained by changes in the inputs included in the ratio. This thesis attempted to describe as much variation in labor productivity for western dragline operations as possible using factors which were readily measurable at 23 strip mines. Although the uncertain portion of productivity can not be defined, the factors which can be identified to exert influence on labor productivity can be manipulated to improve operating performance.

The thesis provides two independent methods to forecast mine labor productivity for new mines and compare an existing mine's productivity with the average of the mines in the study. The productivity comparison allows a mine operator to determine if his mine is unproductive within the unit operations defined in the thesis or for the overall operation. These unproductive areas can then be improved by focusing on the mine factors generated in the associated productivity functions.

The following is a brief summary of the most important conclusions provided by the thesis.

(1) A labor productivity function can be formulated using linear regression techniques and basic physical and quantifiable factors at western dragline operations.

(2) Productivity variation is greatly explained by regressing overall labor productivity on the variables: average coal lift thickness, percentage dragline rehandle material, and average weighted overburden stripping bucket capacity. A standard deviation of 1.73 tons/man-hour and a coefficient of determination of 87.0% are attained.

(3) By separating the production process into primarily independent parts, additional factors are identified which influence labor productivity using a primarily deterministic approach. These factors are defined in the previously presented Table 39 and ranked according to their impact on labor productivity. Some of the factors are not controllable since they are dependent on the characteristics of the coal property. A mine operator should center attention to only the factors that are controllable in order to monitor and improve operating performance.

(4) The factors included in the productivity functions are important to the development of productivity and should therefore be monitored to identify alternative operating techniques which could boost overall productivity.

(5) Numerous meaningful unit operation productivity ratios are interpreted from coefficients resulting from regression analysis of the influential productivity factors.

(6) Maintenance and G&A unit operations on average make up approximately 53 percent of total man-hours in a dragline operation and should be closely monitored for potential productivity gains.

(7) Productivity (tons/man-hour) is not related to a linear function of strip ratio. Strip ratio must be transformed into an inverse relationship in order to simulate linearity.

(8) The weighted average stripping bucket capacity for primary overburden excavation machines has strong effect on overall labor productivity. This factor also has an inverse relationship with overall labor productivity.

One of most important uses of productivity measurement is to rate performance of an operation against a standard level in order to devise methods of improving operating techniques or other factors which influence productivity. This thesis provides the means both to create this standard productivity level and to identify the factors which can improve of the operation in relation to the standard level.

Another use of the developed productivity function is to project or monitor how new technologies relate to the average performance of other mines. An objective is also provided for these new technologies or operating methods to meet in order to be competitive.

RECOMMENDATIONS FOR FUTURE RESEARCH

The list below presents the author's recommendations for further work directly related to the analysis of labor productivity at western dragline mines. The majority of these recommendations relate to limitations and inexplicable variations in the analysis which should be studied in more detail.

(1) Utilize non-linear curve fitting procedures for factors within unit operations which linear relationships could not be developed. Curvilinear and polynomial fitting should be attempted.

(2) Develop an entirely deterministic model for productivity which uses the data acquired by the project to confirm the validity of the model.

(3) Unit operation analysis should be more detailed in order to reduce the large residuals. The unit operations which have residuals with the same sign should be reviewed for bias in the collected data. Table 40 should be used to define the research priority, with the worst fit unit operations studied first.

(4) More detailed data should be collected relating to maintenance and G&A operations so a better understanding in forecasting man-hours can be obtained. In addition, further research should be done on the wide differences in the computed maintenance ratio.

(5) Break down the stripping unit operation man-hours into each stripping equipment classification so further research can be performed on the influences of bucket capacity in the stripping process. Also analysis into the influence of digging technique should be investigated.

(6) The detailed database of surface mining information established as part of the MPA project provides a tremendous base from which research into the dragline operating performance and shovel/truck productivity can be conducted. It is recommended that similar databases be established for other types of coal operations such as contour stripping, room-and-pillar, and longwall mines. A similar database could be developed for eastern mines.

(7) Artificial intelligence techniques for breaking down and interrelating the factors within an operation could be used to further analyze the mining process and labor productivity.

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APPENDIX A

MPA On-Site Questionnaire

Page - 1

ON-SITE MINE INFORMATION WORKSHEET

Mine ID #: ________________
Mine Name: ________________
Mine Owner: ________________
Parent Company: ________________
Specific Mine Location: ________________
____

GENERAL QUESTIONS

1. What efforts have been made to increase productivity historically?
2. Is there an on-going productivity improvement program or only as necessary?
3. What factors are most influential on productivity for your operations?
4. What would help your operations most in regard to productivity?
5. What variables does your company monitor to track specific and/or overall productivity factors?
6. What graphs, relationships, or data would you be interested in viewing to assist your productivity monitoring program?
7. What capital or labor is included to cut costs? (e.g. power plant to reduce electricity costs)
8. Does MSHA man-hours include salary, contract labor, or other manpower?
9. Does your company purchase any outside coal?

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COAL BED(S) RECOVERED

Seam Name	____	____	____
Avg. Thick	____	____	____
Range of Thick	____	____	____
Pitch	____	____	____
% of total Prod	____	____	____
Consistency	____	____	____
Prep recovery %	____	____	____
Density	____	____	____

COAL MARKETS

Product Name	____	____	____
Target Market	____	____	____
Market Distance	____	____	____
Trans. Method	____	____	____
Seams Blended	____	____	____
% of Production	____	____	____
Quality	____	____	____

Contract description (type, term, etc.): ____________________

____

____

Blending techniques utilized? ____________________

____

____

GEOLOGY

Environmental factors in play (toxicity, aquifers, soil): ______

____

____

____

General geologic conditions for mining: ____________________

____

____

OVERBURDEN EXCAVATION

Top/subsoil handling methods? Problems? % of OB?: ____________

Pre-stripping methods? Criteria for use? % of OB?: ____________

Primary stripping methods: ____________

Drilling method and pattern: ____________

Blasting method: ____________

% Cast: ____________

Angles for highwall, spoil, etc.: ____________

OVERBURDEN EXCAVATION (cont.)

Dragline/Excavator production factors:

Models: ______________________________

____

Bucket Sizes: ______________________________

____

Production per unit time: ______________________________

____

Cycle times: ______________________________

____

Availability factors: ______________________________

____

Other comments: ______________________________

____

____

____

Rehandle %: ______________________________

____

Pit dimensions: ______________________________

____

Bench Height: ______________________________

____

OB haulage distances: ______________________________

____

No. of stripping sections: ______________________________

____

____

Main mine operating constraint: ______________________________

____

COAL PRODUCTION

Coal recovery methods (any differences): ____________________
____
____
____
____
____

Haulage methods: ____________________________
____
____
____

Haulage distances: __________________________
____
____

Recoverable Reserves (estimate): _____________
____

Description of preparation & loadout operations: __________
____
____
____
____

Description of maintenance operations: ______________
____
____
____
____

Benefits package: ___________________________
____
____

Morale: ____________________________________
____

APPENDIX B

MPA Mine Data Sheet

Mine Productivity Assessment Data Sheet Page 1

Mine Name ______________________

Data Category	1986 Data			
OVERALL PRODUCTIVITY:	Company Data		MSHA Data	
Coal Severed (tons)	________		________	
Total Man-Hours Worked	________		________	
Avg. No. of Men Employed	________		________	
OVER & INTERBURDEN (OB & IB):				
Topsoil Thickness (in)	________			
Windrow Width (ft)	________			
Dragline OB Moved (BCY)	________		(NO rehandle)	
Rehandle OB (LCY)	________		(loose yards)	
Shovel OB Moved (BCY)	________		(NO rehandle)	
Topsoil Moved (CY)	________		(respread & stock)	
Dozer/Scraper OB (BCY)	________		(prebench & other)	
Bucket Wheel OB (BCY)	________			
Total OB Moved (CY)	________		(sum above values)	
OB Swell (%)	________			
OB Density (#/CF)	________			
Avg OB thickness (ft)	________			
No. of IB Layers	________			
IB Layers Thicknesses (ft)	____	____	____	
Is OB shot? (Y/N)	________			
Avg Blast Pattern (ft x ft)	________			
Avg Powder Factor (#/BCY)	________			
Avg Blast Casting (% BCY OB)	________		(% not handled)	
Stripping Sections:				
Stripping Bucket Sizes (CY)	____	____	____	____
Bucket Scheduled Hours	____	____	____	____
Bucket Operating Hours	____	____	____	____
Bucket Production (total CY)	____	____	____	____
Bucket Rehandle (LCY)	____	____	____	____
Avg One-Way OB Haul (ft)	____	____	____	____
Avg Topography Slope (Deg)	________			
Stripping Capacity	________		(existing equip.)	

Mine Productivity Assessment Data Sheet Page 2

Data Category	1986 Data			
COAL LOADING & HAULING:				
No. of Coal Seams Mined	________			
Seam Names	____	____	____	____
Avg Seam Thicknesses (ft)	____	____	____	____
Avg Seam Pitch (Deg)	____	____	____	____
Avg Seam Recovery (%)	____	____	____	____
Avg Coal Density (#/CF)	________			
Is Coal Shot? (Y/N)	________			
Avg Blast Pattern (ft x ft)	________			
Avg Powder Factor (#/ton)	________			
Is Coal Ripped? (Y/N)	________			
Loading Bucket Sizes (CY)	____	____	____	____
Bucket Scheduled Hours	____	____	____	____
Bucket Operating Hours	____	____	____	____
Bucket Production (tons)	____	____	____	____
Avg One-Way Coal Haul (ft)	____	____	____	____
No. of Coal Lifts	____	____	____	____
Acres of Coal Mined	________			
Max. Water Pumped (gal/day)	________			
MINE GEOMETRY:				
No. of Active Pits	________			
Avg Pit/Bench Width (ft)	________			
Avg Pit/Bench Length (ft)	________			
Avg Bench Height (ft)	________			
Avg Spoil Angle (Deg)	________			
Avg Highwall Angle (Deg)	________			
Avg No. of OB Benches	________			
Total Acres Disturbed	________			
Ramp Interval Distance (ft)	________			

Mine Productivity Assessment Data Sheet Page 3

Data Category	1986 Data	
LABOR:		
Workforce Organization	________	
Avg Overtime (%)	________	
Absenteeism (%)	________	
Contractor Use? (Y/N)	________	(not in MSHA m-hr)
Corporate Use? (Y/N)	________	(not in MSHA m-hr)
GENERAL:		
Type of Market	________	
Date of 1st Production	________	
Coal Production Capacity	________	(existing equip.)
Avg Primary Equip. Avail. (%)	________	

Mine Productivity Assessment Data Sheet Page 4

MANNING TABLE:

Unit Operation	Average No. of Men	1986 Data Employee Man-Hours	Contractor Man-Hours
Reclamation			
Stripping			
Coal Loading			
Coal Hauling			
Preparation			
Loadout			
Maintenance			
Mine Support			
Gen & Admin			

UNIT OPERATION DEFINITIONS:

Reclamation	Topsoil, subsoil, regrade, planting, environmental, ponds.
Stripping	Drill & blast overburden, overburden and interburden removal.
Coal Loading	Cleaning, drill & blast or rip coal, load.
Coal Hauling	Hauling coal to dump point.
Preparation	Crushing, screening, washing, blending.
Loadout	Coal product loading into trucks or railcars.
Maintenance	All equipment and facilities.
Mine Support	Roads, pumping, ash disposal, all other direct mine support activities not listed above.
Gen & Admin	Upper management, engineering, office, corporate, NOT including unit operation supervision.